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89-628

DEPARTMENT OF NATIONAL DEFENCE

DEFENCE RESEARCH ESTABLISHMENT OTTAWA

CONTRACTOR REPORT DREO/PSD/CPS - 24/86

A PROGRESS REPORT ON THE DEVELOPMENT OF A LIST OF CRITERIA FOR THE EVALUATION OF DIFFERENT SHAPE MONITORING TECHNIQUES

AND

INTERIM REPORT ON THE QUANTIFICATION AND SUMMARIZATION OF HUMAN BODY SHAPE

By

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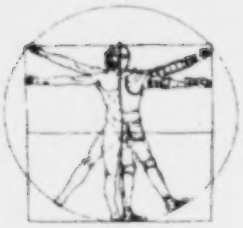

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INTERIM REPORT ON THE QUANTIFICATION AND SUMMARIZATION OF HUMAN BODY SHAPE

prepared for

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INTERIM REPORT ON THE QUANTIFICATION AND SUMMARIZATION OF HUMAN BODY SHAPE

This short report has been prepared to inform the Scientific Authority of the progress that has occurred over the last six months on this project.

General

As previously discussed, two objects have been identified as being suitable for imaging testing. These are the NRC Moire standard test device and an anthropometric headform provided by DREO.

Both devices have been utilized in the testing to date. The NRC test device will be used to check system accuracy, image and size. It was initially hoped that all systems could be compared to each other using this test device. The headform has been used to ensure that a known, difficult human shape can in fact be monitored by a given system. Later this headform, as well as another ATD headform, will be used for general averaging purposes when the best shape monitoring technique has been identified.

Conferences

Two conferences were identified that we felt would add to the general knowledge of these techniques.

The first, The International Society for Photogrammetry and Remote Sensing had their annual meeting held in Ottawa, June 16-19, 1986. Mr. Roger Perry of Biokinetics attended. His general comments on this conference follow in this section.

The second, The Fourth International on Surface Topography and Spinal Deformity will be held September 29, 30 at Mont Ste Marie and Mr. Gallup will attend.

The ISPRS conference held in Ottawa this summer was judged to be of assistance. It centered around Real-Time Photogrammetry which would be of assistance in monitoring human body shape. Many of the papers were of a highly technical nature. Most of the papers seem to fall in two major categories: (1) A description of hardware and calibration procedures (usually revolving around slight modifications to existing photogrammetric equipment) and (2) a description on the background mathematics of various photogrammetric techniques.

The entire proceedings have been included under separate covers. Papers providing some worthwhile information to our project include:

Photogrammetry

1. "Application of Non-Metric Photogrammetry in Archaeometry". Ogleby, Pg. 102.
2. "Biostereometric Methods for the Study of Body Surface Motion During Breathing". Adams & Klein Pg. 263.
3. "Recording and Replicating a TSIMSHIAN Stone Mask by Close Range Photogrammetry". Sawyer & Bell, Pg. 510.

Raster

1. "Test of Photogrammetric Accuracy for Mensuration of Aerospace Tooling". Robertson, Pg. 232.
2. "On Line Restitution in Biostereometrics Using One Photogram and a Metric Projector". BaJ & Bozzolato, Pg. 271.

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Moire

1. "The Ordering of Ordinary Moire Fringes by Photogrammetric Analysis". Xinhong and Pekelsky, Pg. 294.

ISIS

1. "Measurement and Analysis of Human Back Surface Shape". Turner-Smith and Harris, Pg. 355.

Other

1. "On Line Three-Dimensional Light Spot Tracker and Its Application to Clinical Dentistry". Mesqui, Kaeser, Fischer, Pg. 310
2. "A System for Orientation of Non-Metric Camera Image Plane". Muftuoglu, Pg. 318.
3. "New Photogrammetric Instrumentation for Use in Medical Applications". Robertson, Pg. 332.
4. "A Real-Time System for Object Measurement with CCD Cameras". EL-Hakim, Pg. 363.
5. "Automated Three-Dimensional Measurement Using Stereo CCD Camera in the Application to Close Range Photogrammetry". Murai, Pg. 409.
6. "Photogrammetric Plate Measuring Facilities at NPL". Oldfield, Pg. 541.

Of Secondary Interest

1. "Determination of Three Dimensional Coordinates of the Object Points By Means of X-Ray Aimed Pictures". Cherney, Pg. 122.
2. "Using the Scanning Electron Microscope to Determine the Uneveness of grain Surfaces and to Draw Contour Lines". Weigian, Guangwen, Pg. 151.
3. "The Application of Stereo Video Photogrammetry to Visual and Related Ergonomics". Bedwell & Mahani, Pg. 279

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4. "Photogrammetry and Architecture the Anatomy of Bernini's Buldachin (1624-33)". Kirwin & Thiene, Pg. 473
5. "High Resolution Moire Photography". Forno, Pg. 529

These papers will be used to further describe each of the chosen systems in the final report. More importantly perhaps, this conference allowed us to meet directly with those individuals previously noted as being at the leading edge of this technology. This is especially true, in regards to techniques that we have already identified as being pertinent to our needs. This includes Turner-Smith (ISIS) and G. Robertson (Raster). Information gained from both these gentlemen has already been used in the assessment of these techniques.

Shape Monitoring Techniques Update

Raster

Both the NRC test device and the DREO headform have been photographed. Photographs of the two objects with projected patterns on them have been included in Appendix A. The object point co-ordinates for the NRC test device have been forwarded and received by us. Complete details of the methodology employed and results of testing will be described in the final report on this phase of the project.

Laser Scanning

Both the headform and NRC Test Device have been measured and the data tapes have been forwarded by Hymark. Grey images of these objects have been included in Appendix B.

However, problems do exist with this technique at this time. Most of these problems are due to the fact that it has just recently been developed. Presently it can only monitor approximately 70% of NRC test device. A larger image will be available in the near future but at present this device can only monitor to this size. We feel that this is adequate for our purposes at this time and that when image size increases (through hardware upgrading) this technique will meet the primary requirements as laid out previously.

Sonic Digitization

The NRC Test device has been measured using GP-8-3D Sonic digitizer. The data is being stored here at Biokinetics and will be transmitted to DREO shortly. Some of the problems with this device have already been discussed with you and will be documented in the final report on this section.

Light Sectioning

A major problem has occurred with the equipment at West Park Research. It physically can not monitor the NRC test device at this time. It will not fit in the sensing booth. West Park Research have, however, just been awarded a grant to enlarge their image facilities by Health and Welfare and

Geoff Fernie has assured us that it will be possible to measure this device early in the new year.

If agreeable to you, we propose to go ahead and monitor this device with the DREO headform, and unless it proves completely unacceptable, measure the NRC test device early in the new year. We feel that this will prove adequate.

ISIS

Software problems have forced cancellation of the testing in August and we expect the testing to be carried out in early October with no further delays.

Automated Moire

No further advances by NRC have been made on this technique to date. Questions still remain as to whether this will ever prove to be a viable technique.

NRC personnel have requested manpower from Biokinetics in an attempt to finalize the device. Whether this proves feasible remains to be seen. Continuing with this technique will be discussed with the contractor at this time.

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Summary

The data acquisition activity of this program is nearly finished. The following activities will deal with preparation of the acquired data for future processing and with the processing of the data. To this end the "Kermit" system has been obtained from the NRC. It is a complete package that includes versions for many different systems including Data General, VAX, PDP11, IBM PC, etc... Distribution of this public domain package will simplify the task of transferring the data gathered by different agencies to the DND Data General computer (or to any other system that can offer some form of advanced processing).

The likely route that this project will take will be to transfer the data to the system at Shirley-s Bay. Using the "Grip" programming facility, the data will be input to the Uni-Graphics CAD package. From there, surfaces will be recreated and measurements will be made from the previously acquired data. This will permit an analysis of the quality of the data, the quality of the acquisition system already having been established.

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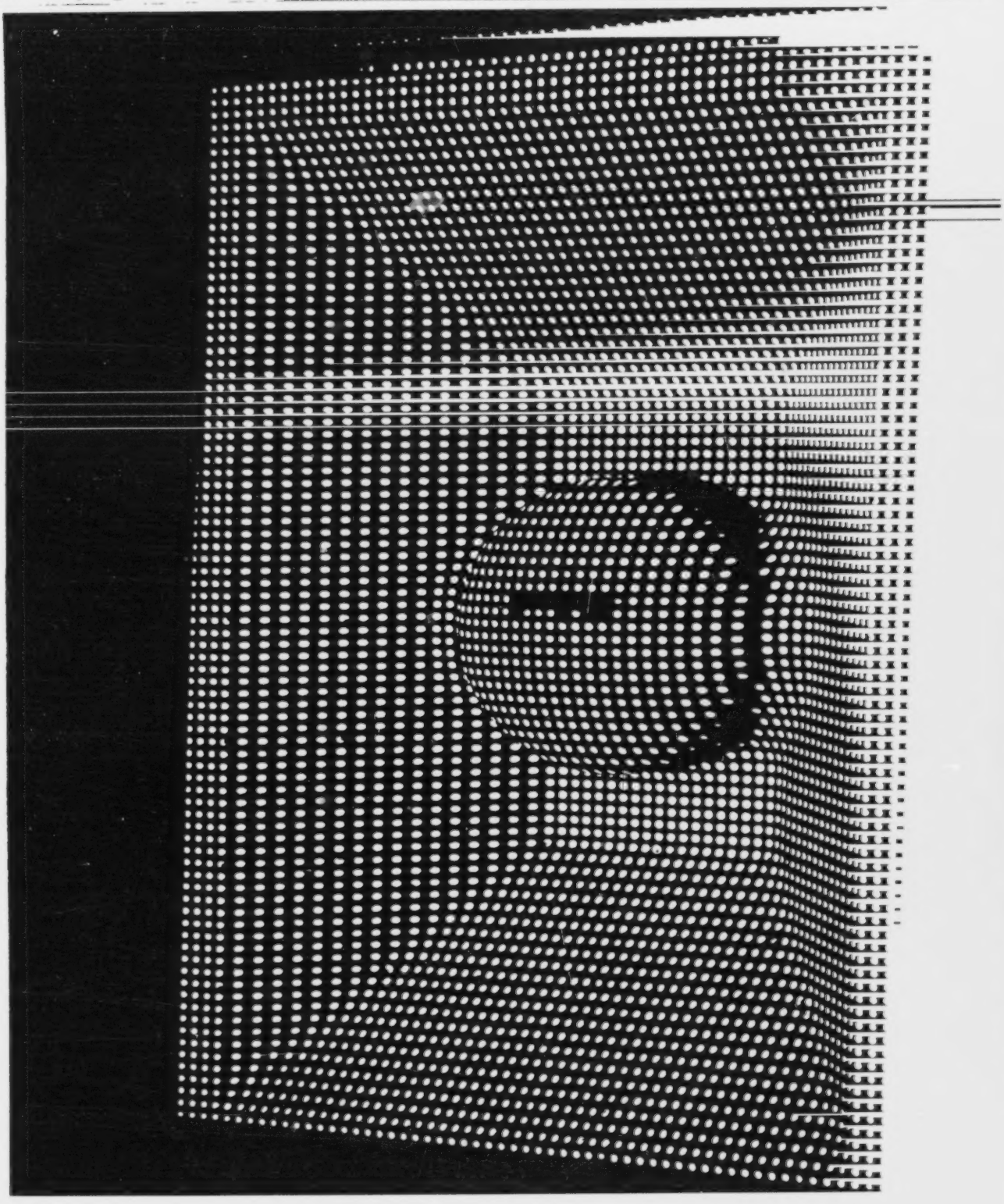
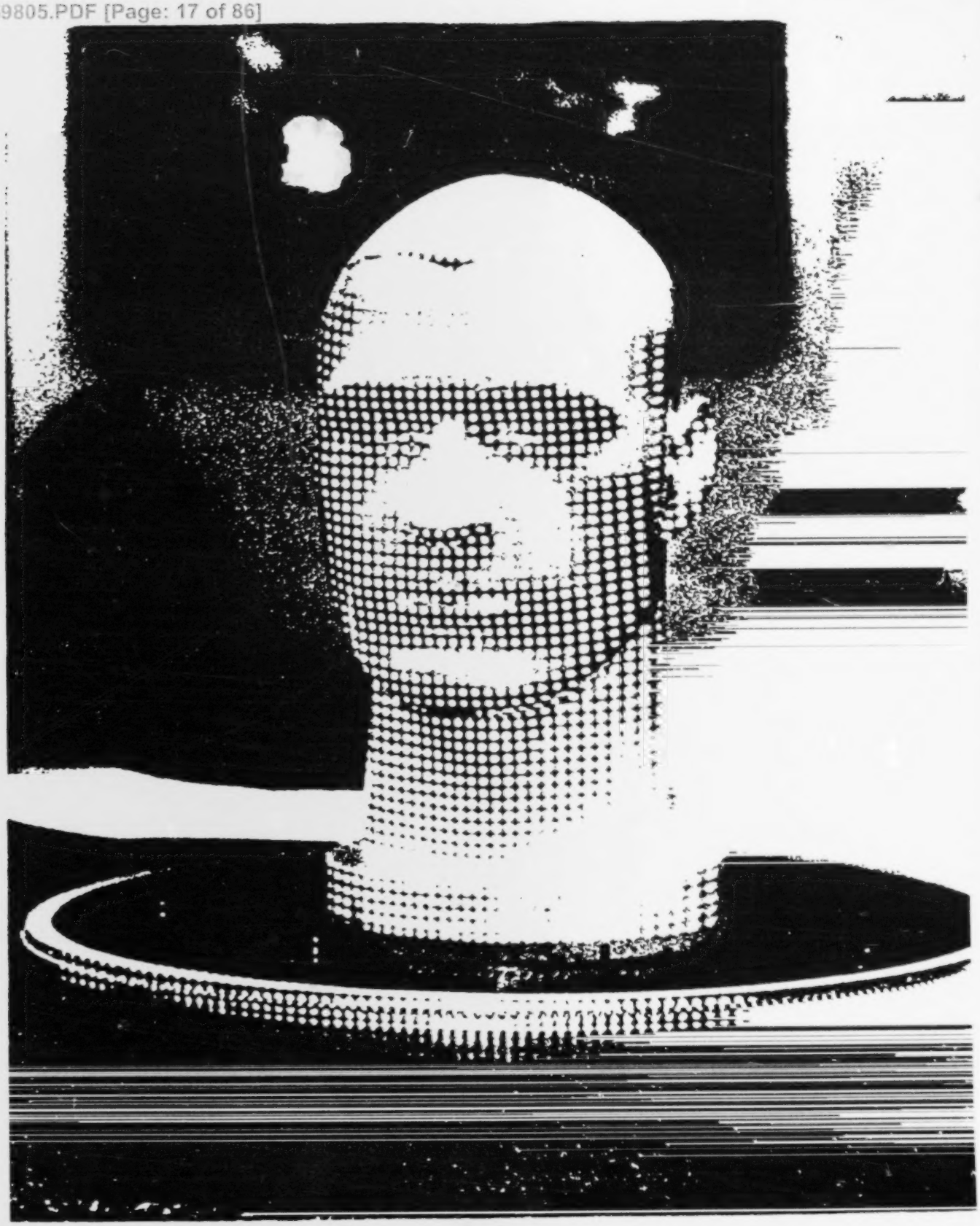
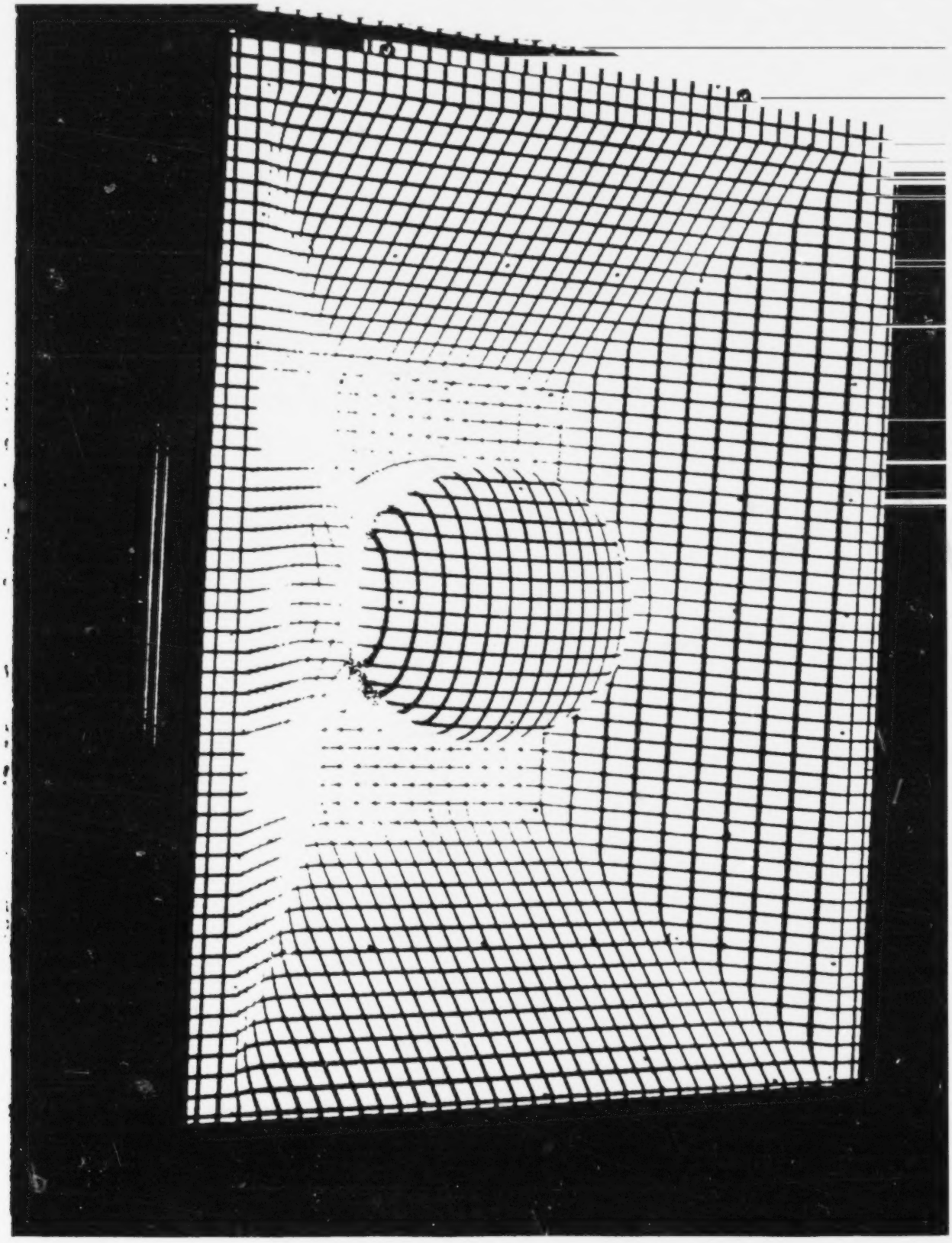
APPENDIX A







APPENDIX B

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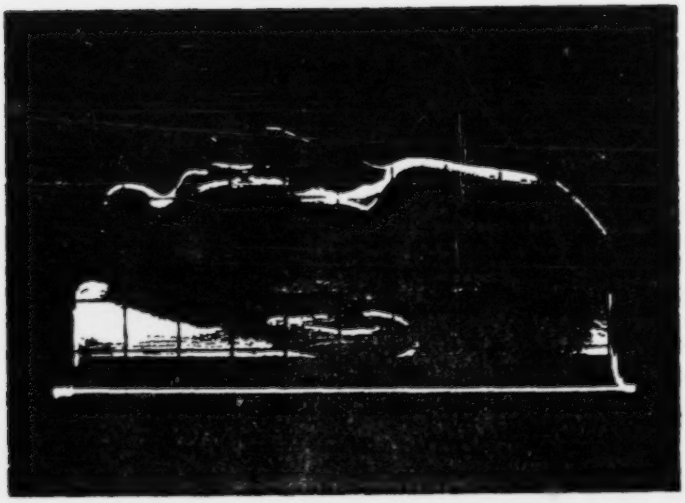

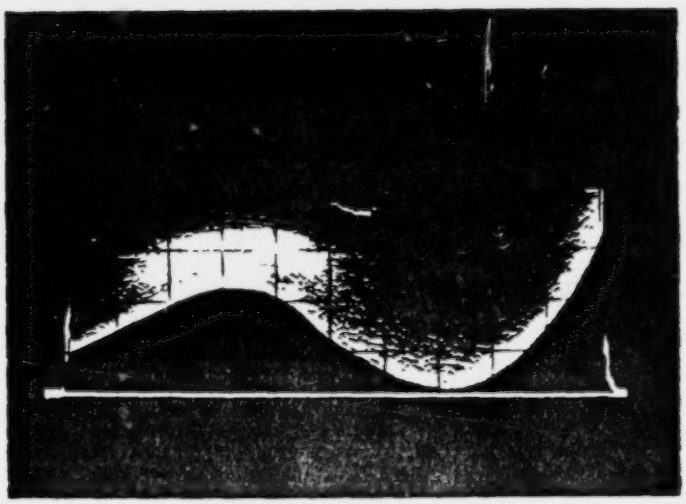

FIGURE 1

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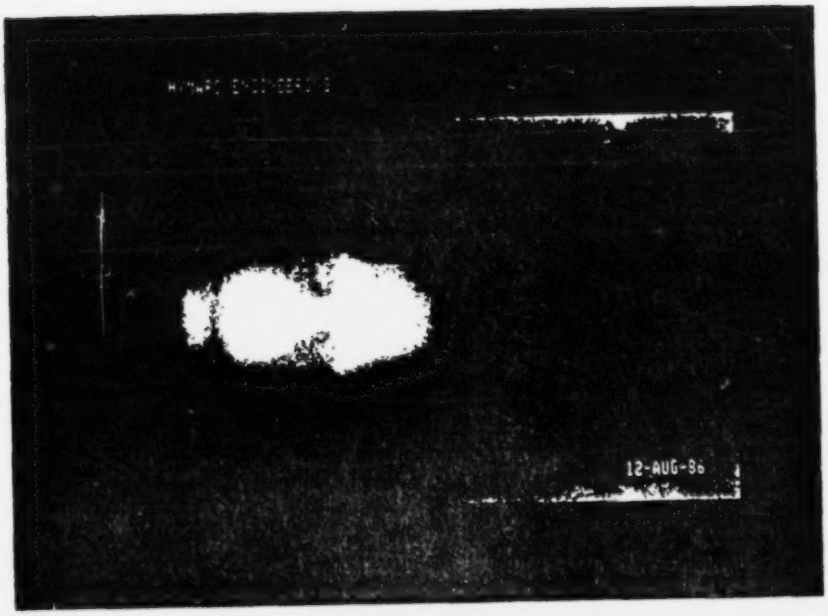

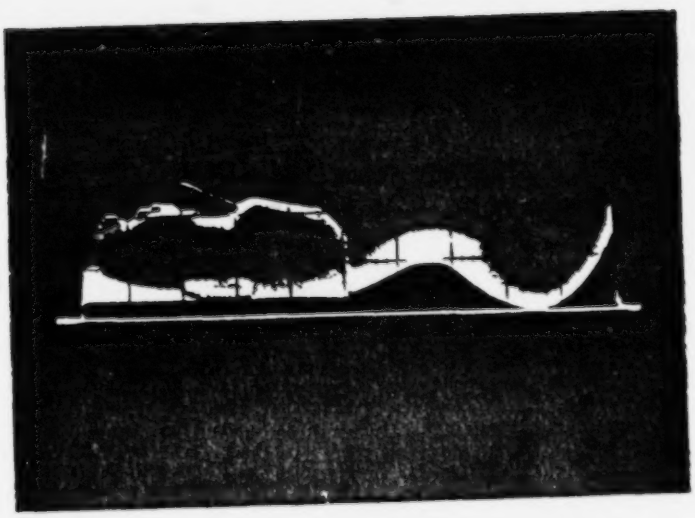

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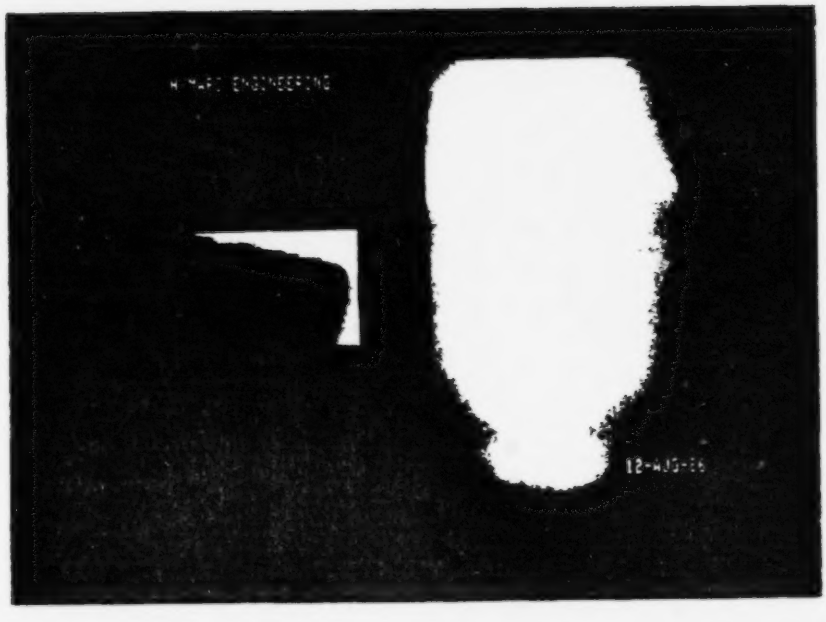

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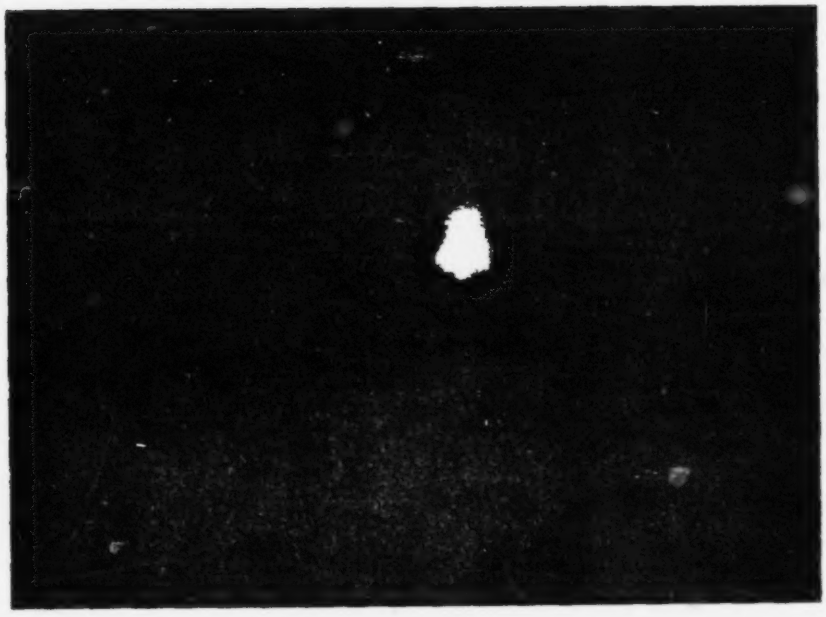

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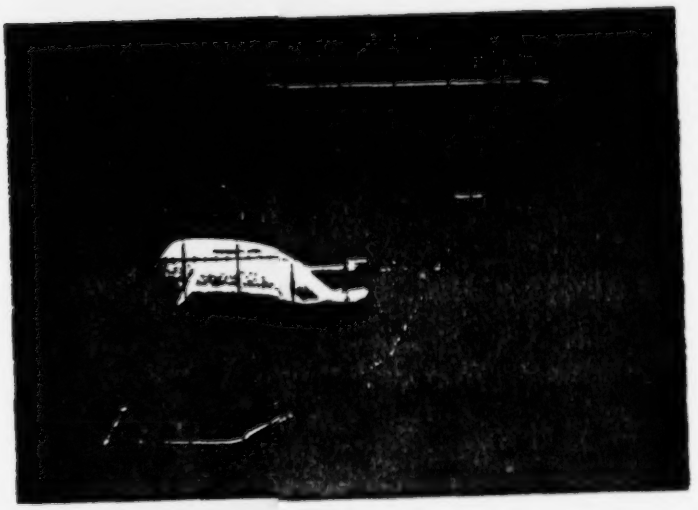
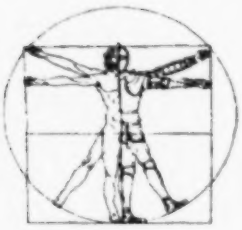


FIGURE 5



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Department of National Defence
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Contract #03SV.97714-4-2812

May, 1986
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This short report has been compiled to inform personnel at DREO of the advances that have been made over the last few months as well as to report on the planned testing to be undertaken over the next six months.

1.0 TEST OBJECT DEVELOPMENT

Over the past few months, consideration has been given to identifying ideal test objects. From discussions with personnel at Biokinetics, NRC and at DREO, it appears that appropriate test objects have been isolated.

The first test object will be the standard Moire test object developed by NRC. It represents a quantifiably defined shape possessing a level of complexity that should clearly identify.

It is the same size as a human torso and therefore will be required to meet one of the primary criteria previously set.

It will be acquired on a loan basis from NRC over the next six months. Negotiations have already started on time scheduling and it is hoped that this will meet with their approval.

A second more complex shape has also been identified. They are the newly developed headforms fabricated by Anthropology Research for DREO. Discussions have been entered into between Biokinetics and DREO and it is anticipated that there should be no problem in borrowing them.

2.0 TESTING FACILITIES

As previously noted in the last report, six techniques were identified as warranting further work as opposed to the four noted in the proposal. During discussions with groups using all of these six techniques, all techniques appeared to be adequate, so preliminary test scheduling has commenced on all of them.

At present all the groups have shown interest in participating in the project and tentative testing dates have been scheduled. This will depend upon NRC's requirements for the standard test device.

The six techniques and a corresponding tentative schedule has been included in Table 1. A short discussion on new developments concerning each technique follows.

TABLE 1: PRELIMINARY SHAPE SCHEDULE

TECHNIQUE	IDENTIFIED GROUP	KEY PERSONNEL	TENTATIVE SCHEDULE	RESEARCH PERSONNEL
Laser Scanning	Hymark, Ottawa	F. Livingston	June	AS/BG
Laser Sectioning[1]	West Park Research	G. Fernie	August	JN/JP
Rasterstereo[2]	Gary Robertson/ADGA	G. Robertson	Flexible	RP/BG
Moire	NRC/Physics	J. Pekelsky	October	BG/NR
Isis[3]	MERU - B.C.	M. Bannon	July	JP/NR
3-D Sonic Digitizing	Biokinetics	A. St-Laurent	May/Flex.	AS/TG/N

NOTES:

1 Visits already undertaken

2 Photographs to be taken in house/ data processed in California

3 Visit planned to MERU June 16/17

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3.0 IMAGING TECHNIQUES

3.1 Raster Stereo Photography

Discussions have been held with Mr. Gary Robertson and Mr. Ray Epp of the ADGA group (Gary Robertson and Associates and ADGA, Ottawa, are associated firms). We have been informed that imaging is relatively easy and could be undertaken by Biokinetics. The resulting photographs could then be sent to Gary Robertson for processing.

The photographs will be digitized using the PDS Micro-D photo digitizer. This device claims to have an accuracy of .0005 inches in a 3 ft square.

Specifics as to test object placement, camera types and any special reference tagging of the object will be acquired in the near future. Some of the brochures for this system have been included as Appendix 1.

Gary Robertson will be presenting a paper at the stereophotogrammetric conference being held here in Ottawa, June 16-20.

Dipix, Ottawa, also have a photo digitizing capability and it may prove interesting to compare these two groups.

3.2 Laser Sectioning

Members of Biokinetics Staff met for a second time with Geoff Fernie of West Park Research on Thursday, March 20, in Toronto.

There are three laser-sectioning shape sensors at this centre.

1. For the quantification of a leg stump, used in conjunction with prosthetic manufacturing.
2. For the quantification of a foot - a system is being developed for a large Swedish shoe manufacturing company.
3. A closed system for quantification of small objects.

Rapid digitization means the systems are ideal for quantification of human shape, and the accuracy is good.

Problems with the system include an inability to recognize patterns. At present, the digitized shape is compared, using certain predetermined co-ordinates, with an existing shape stored in the computer.

There is no summation or averaging of the data per se. This is true of all systems and discussions with NRC indicate that it remains a rather formidable problem in their research.

It is planned to test this technique during August.

3.3 Laser Scanning

Contact has been made with Hymark and a proposal has been received by Biokinetics for the testing of this system. The costs involved are judged to be reasonable. Testing has been scheduled for mid-June.

Data processing of this image appears to hold no problems. The number of points collected are the maximum allowable with this system and the data can be displayed at varying levels.

In short, Hymark will provide scans of the three test objects (standard test object and two headforms). It will provide photographs of the gray scale images and will provide image data on an IBM/PC diskette.

3.4 Moire

Further discussions have been conducted with J. Pekelsky of the physics department of NRC on an automated Moire technique.

Work has progressed satisfactorily since initial contact was made with Pekelsky. Some problems still exist with the software but these are being ironed out. Difficulty may arise, however, when the data has to be transferred to another system. They can not schedule any time for this project until October because of prior committments.

The system has been set up so that digitized data can provide a topogram of an object. Moire pictures are taken of the test object. NRC and DIPIX (of Ottawa) have been working on a means of automatically digitizing this data. At present, they are using an EIKONIX digitizing camera. It is estimated that it would require only 4 mimutes to fully digitize the test object. To provide the accuracy required, the digitized points should be approximately 1mm apart. For the standard Moire test device this would require 500,000 points.

The data is transferred (via a FORTRAN 77 program): designed to capitalize on DIPIX's Aries 2 imaging hardware. Any transfer of data to another system will most likely require writing of specific interface programs.

Specific timing of this work has not been confirmed as yet. Further discussions will have to be held with both NRC and DIPIX, prior to firm

scheduling. Pekelsky felt that October might be a good month and that the technique should be even more advanced that it is now.

3.5 ISIS

ISIS is presently being used operationally by the Medical Engineering Resource Unit, (MERU), in British Columbia. A meeting has been scheduled for personnel of Biokinetics to view an ISIS demonstration on Monday June 16, 1986 in Vancouver. A tentative test date of mid-July has also been scheduled.

At present the ISIS device is being used to examine patients for scoliosis. The data collected is used for long term tracking of a patient's condition.

One problem noted is that the device has demonstrated some variability in system calibration from day to day of a few mm.

The ISIS device scans the object/human to be measured and provides 3-D information. At present, it cannot identify specific points, as no routine or software exists. The Oxford group may have developed the software to alleviate this problem or MERU could modify the present software so it can identify markers on the object and use them as reference points. This appears to be a rather common problem with most (if not all) of the techniques. These markers could be used to further determine the accuracy of the measuring device. Bannon suggested these markers be standard points to test all the shape measuring devices.

The cost of measuring the test object would depend on the modifications they would have to do on their software and the number of points which would be measured.

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The data acquired from the scans are stored on floppy disk. The device is capable of downloading the file to another computer. At present it is not known what in format this could be done but it does not appear to pose much of a problem.

3.6 3-D Sonic Digitizer

Sonic measuring systems were one of the methods isolated in Phase ! as having potential for quantifying complex shapes. A commercial three dimensional sonic digitizer, the GP-8-3D was acquired.

Over the last few months a high proportion of the work being carried out on the shape project has centered around this device.

The GP-8-3D sonic digitizer has been at Biokinetics for several months. In this time the system has been set up and is now running in conjunction with an IBM PC AT microcomputer. Calibration has been carried out and some deficiencies in the software supplied with the system have been rectified. Initially the software only processed three microphone channels and ignored the fourth. It now selects the best three channels from the four available. This is necessary to minimize problems with shielding of the emitters by the probe and test piece. The software has also been converted to Pascal to improve interfacing with the AT and increase processing speed.

The software will support variations in the probe geometry. A probe for measuring cavities was fabricated and successfully tested.

The system works as designed and can achieve the performance claimed, but several difficulties with using sonic digitization in this application have already become apparent.

1. The digitizer is sensitive to movement of the offset probe. This must be stationary when a reading is made. (The emitters spark every 25ms so a total of 50ms of steadiness is required).

2. The microphones are sensitive to reflections. A clear area of at least 8m radius is required around the equipment. Alternatively, all reflecting surfaces need to be covered with sound absorbing material. Reflections from the probe itself add to these problems.

3. Spurious points generated by echoes and movement of the probe are difficult to extract from the good data.

4. The accuracy of the system is reduced by propagating errors in the computations (approx. $\pm$ 1mm).

5. The construction geometry of the offset probe limits the orientations in which the probe can be used. The plastic base, in which the emitters are mounted, interferes with or blocks the direct line between the emitter and the microphone. When this occurs the microphone will sense a reflected pulse from the base. This gives a significant error (approx. 5mm). The errors resulting from the construction of the probe can be reduced by spacing the emitters further apart and reducing the blanking effect of the base itself. The ideal solution to this is to use a single emitter with no offset. The use of such a probe is not always possible and requires increased care by the operator.

6. The system at present is a manual system requiring a skilled operator to produce acceptable results. To carry out a complete scan of a body region would be time consuming. Work is continuing with this

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technique and it is felt that many of the difficulties will be overcome.

In a further development in this area, we will be visiting Carl Saunders along with the MERU group in Vancouver. He has extensive experience with the manufacture of prosthetic devices and is currently developing a mechanical digitizer and is intending to use it to measure human shape.

APPENDIX 1

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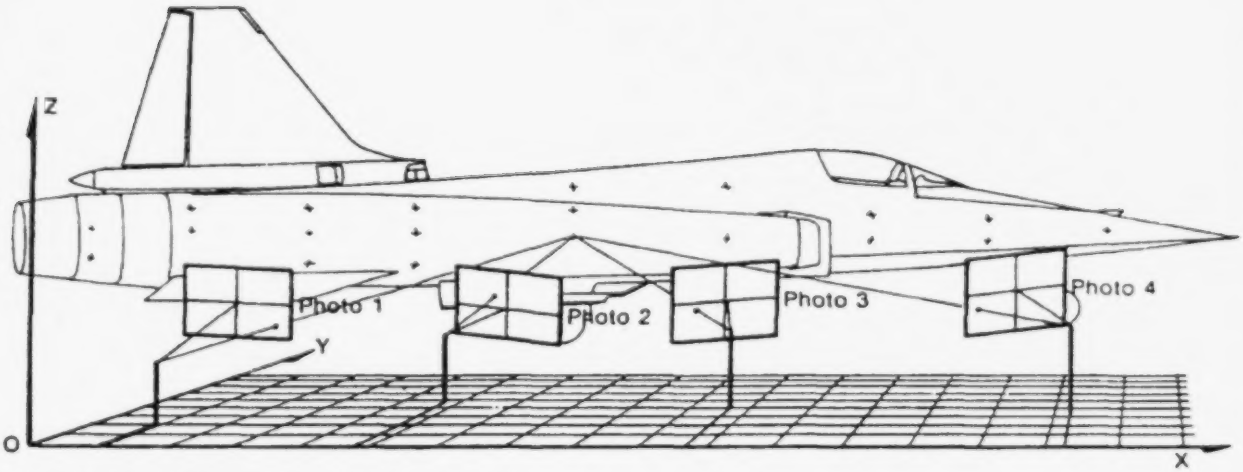
NEW PRO

For problem measurements — Photogrammetry with the PASS 2000



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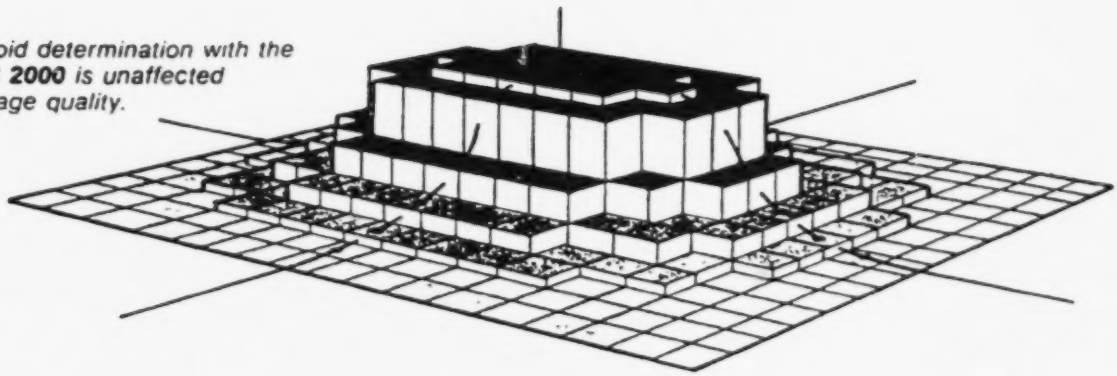

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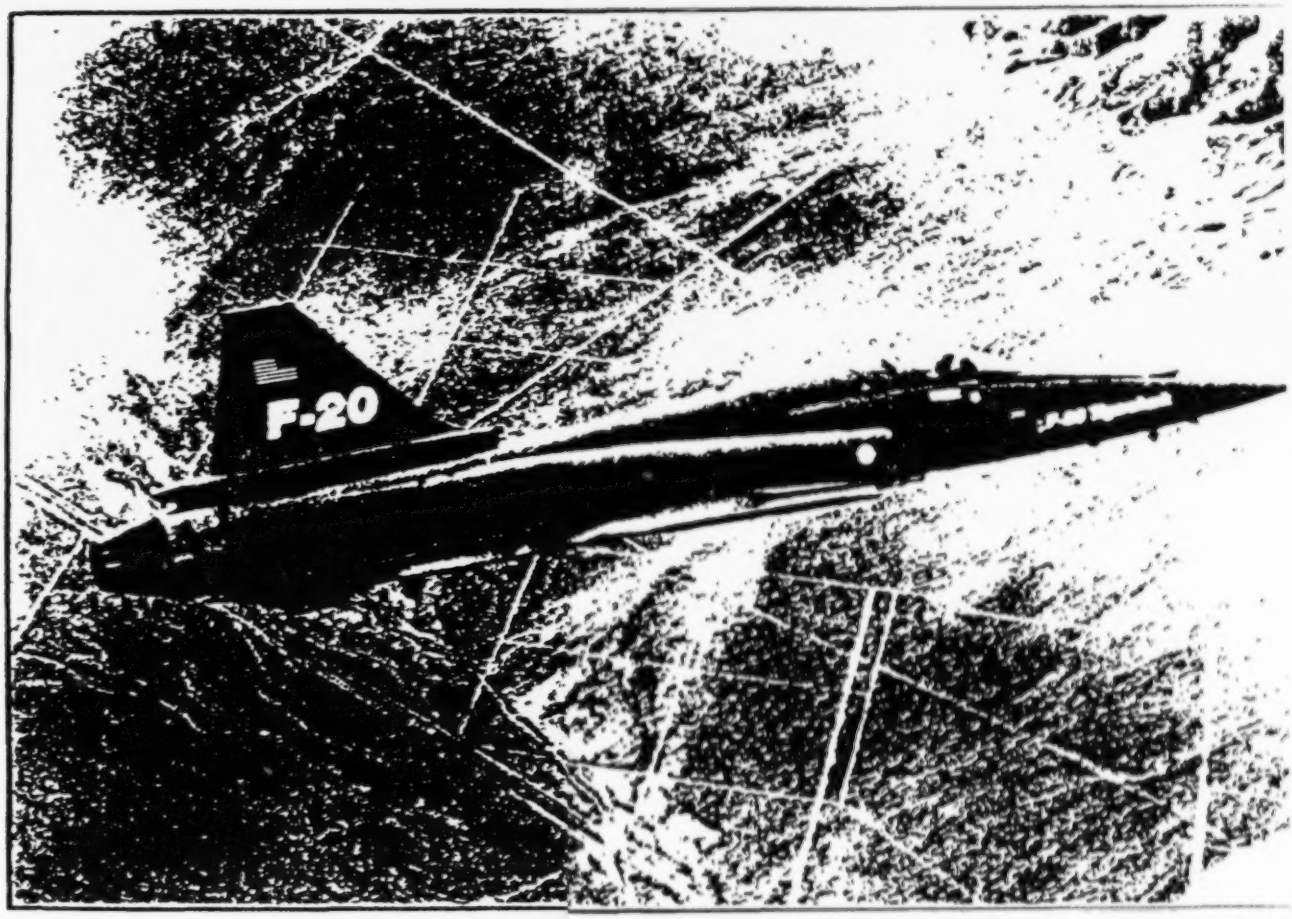

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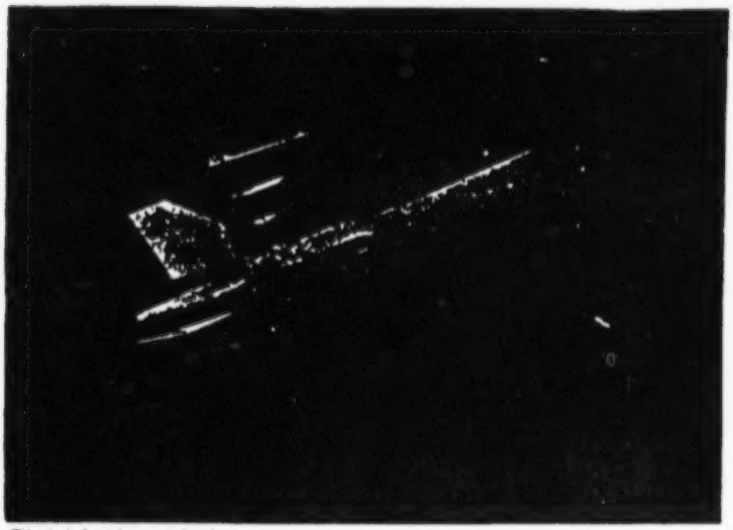
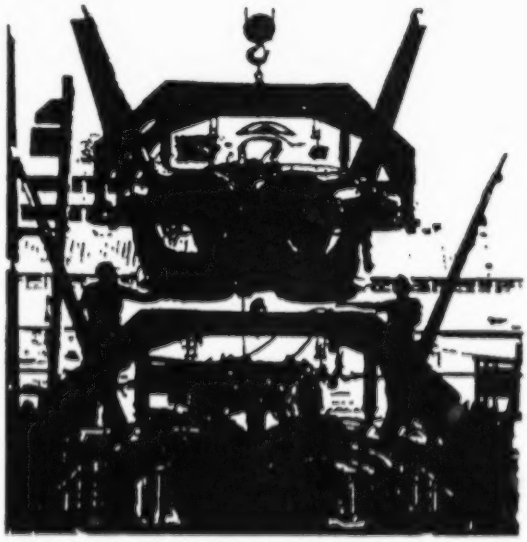
APPLICATION

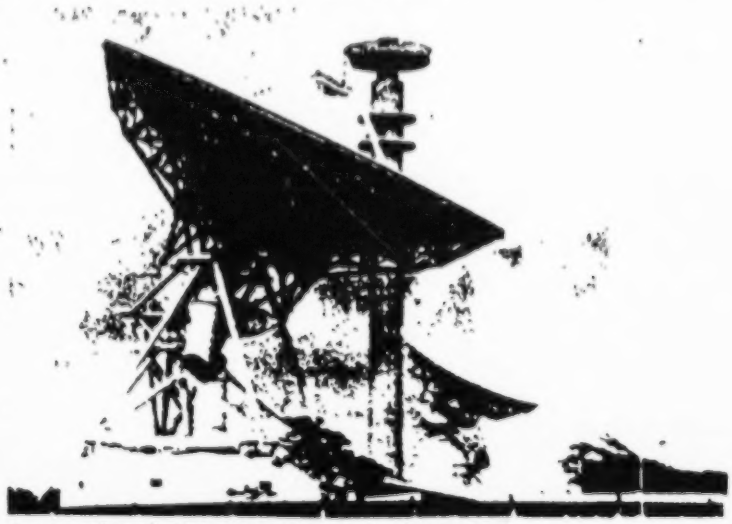
PHOTOGRAMMETRI APPLICATIONS



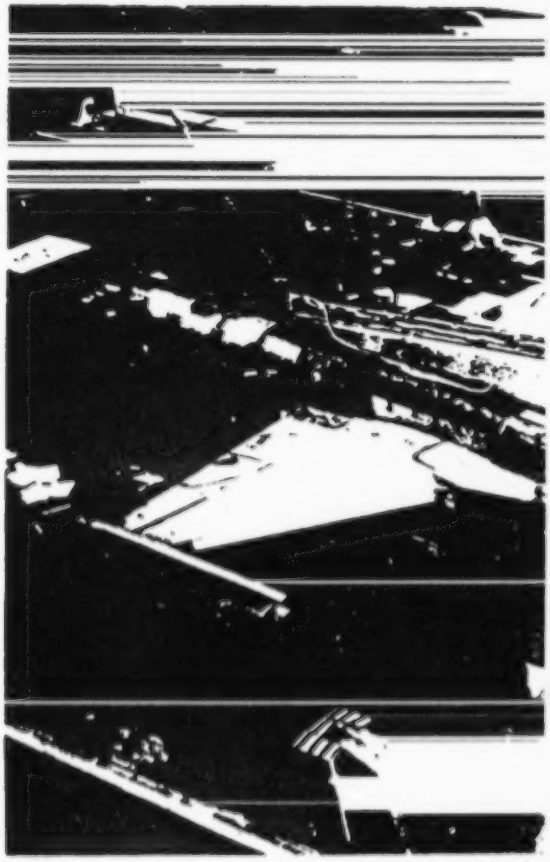
Flight test analysis



Verification of subassemblies



Large structure geometry and alignment

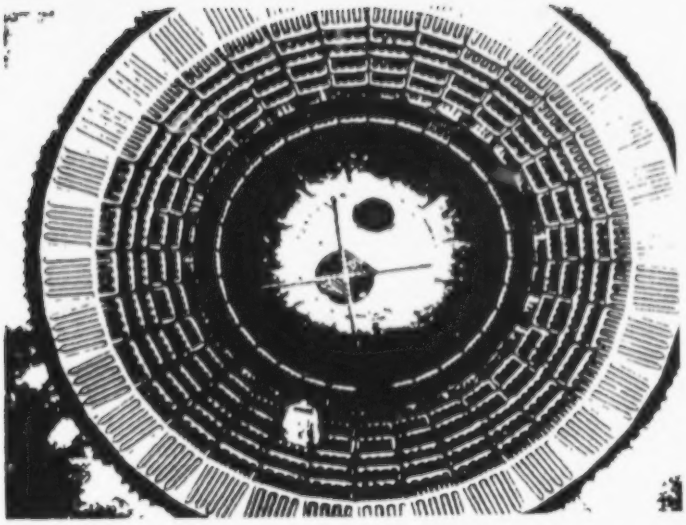


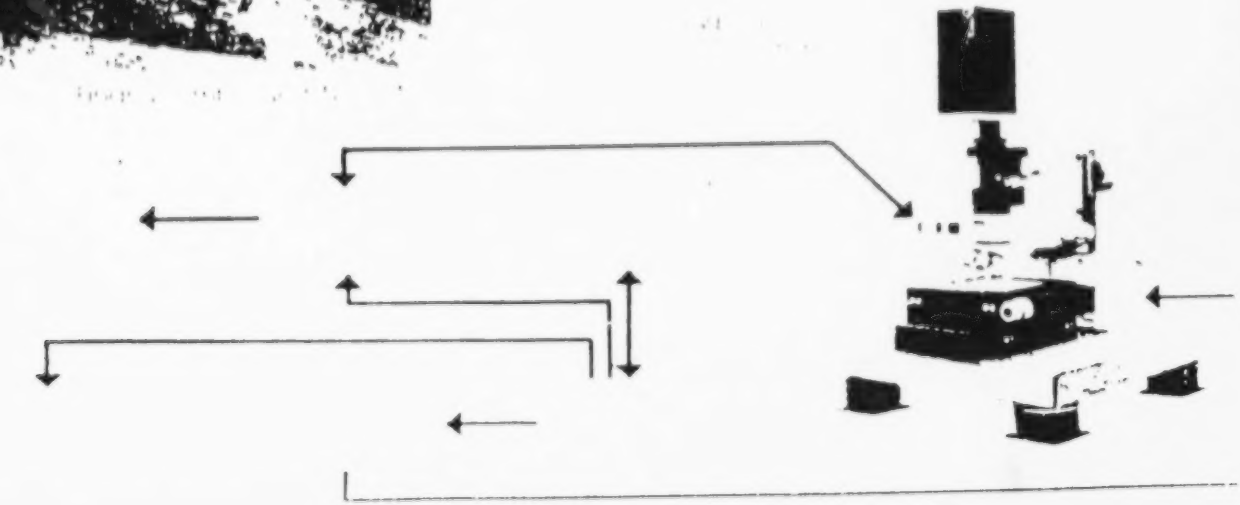
- Quality control of assembly fixtures for tool inspection
- Monitoring alignment of manufactured components to insure proper mating with c parts
- Determining the deformation of test pieces different area or point loads
- General deformation studies at takeoff and landing
- Spatial determination of air flow patterns a wind tunnel measurement of models
- Analysis for flight testing remote piloted vehi
- Provide precision control, for use in robotics

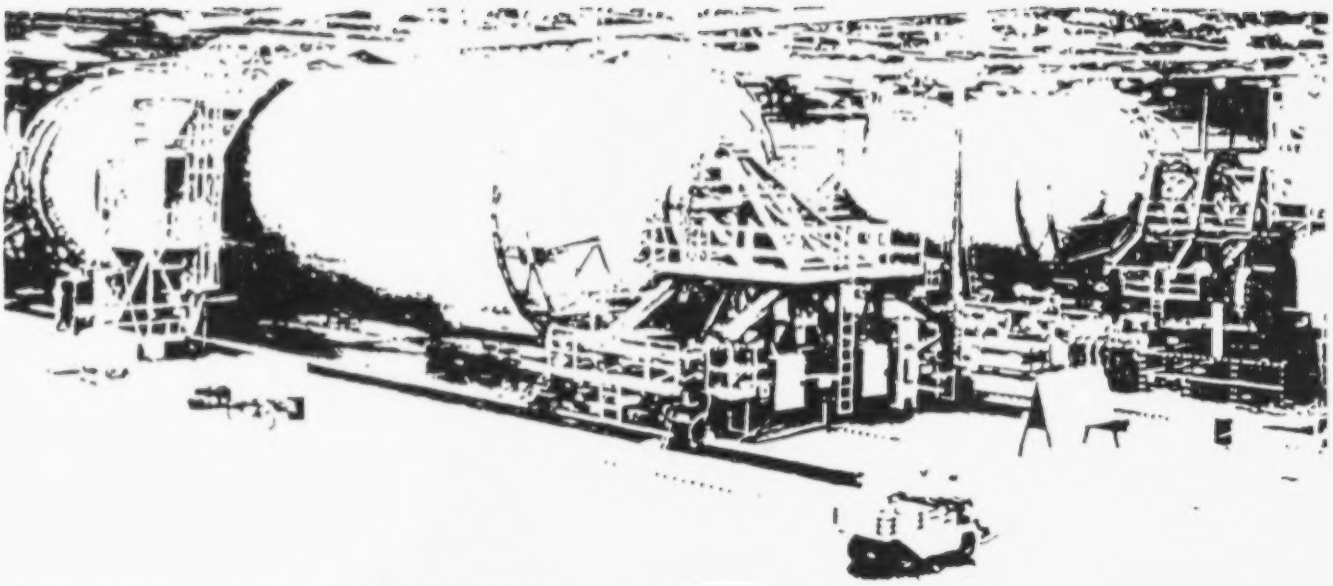
- ...alytical photogrammetry
- ...eal time video image processing

...curate digital measurements

...ll measurements are automated.







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gr

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P-E/RPI PASS 2000 APPROACH

In close-range photogrammetry it is a truism that, all else being equal, the more accurate the photocoordinates, the more accurate the computed object measurement. Conversely, the more accurate the determination of target photocoordinates, the more total error budget that can be distributed among the other factors affecting overall system accuracy such as uncalibrated camera and film distortions, object movement, number and placement of cameras, refractive inconsistencies, etc.

Optimum visibility for a given-sized target is achieved with a circular black-and-white configuration. The size of the spot is usually chosen so that its photoimage is 100-150 microns across. However, this image is seldom circular (due to camera tilt) and never sharply-defined (due to film emulsion granularity). Indeed, the grainy appearance of the target photoimage is exacerbated by viewing under optical magnification, the technique universally employed in position-measuring instrumentation. The mensurational problem of close-range photogrammetry, then, is one of determining, with a high degree of accuracy, the centroid of a diffuse elliptical photoimage. And, it might be added, doing so in a reasonable amount of time.

The approach chosen for the PASS 2000 is to utilize the precise photodigitizing capabilities of the Perkin-Elmer PDS family of flatbed optical scanners to generate an accurate "numerical image" of the scene recorded on the photographic emulsion. The location coordinates and photometric values of literally thousands of photo elements, or pixels, are used to make a mathematical determination of each target image centroid. The accuracy of this measurement is unaffected by image quality as long as there is a measurable photometric difference between the target image and its background. Therefore, target images so far out of focus as to

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be visually unrecognizeable may still be used for the photogrammetric determination of object coordinates.

This technique has been used for many years by astronomical observatories all over the world to make precise measurements of stellar and galactic images on star plates.

Since 1971, more than 40 observatories have considered the PDS instrument to be their standard of accuracy for this type of work. Sophisticated algorithms have been written which, in conjunction with meticulous environmental controls and positional calibration procedures similar to those used in the PASS 2000, yield measurements accurate to a fraction of a micron. While the centroid algorithm used in the PASS 2000 has been simplified for thruput considerations, accuracies better than 2 microns have been demonstrated in a standard "laboratory environment".

The accuracies achievable with the PASS 2000 are independent of the operator and may be expected day-in, day-out without fatigue or subjective interpretation. Thruputs of two seconds per target, including stage moves, are realizable. The X, Y photocoordinates of each target image are automatically determined, then input to a data reduction computer for use in a photogrammetric solution of object X, Y, Z coordinates.

The photosensor used in the PASS 2000 is a CCD camera using a 320 X 240-element area array. This is optically reduced so that it covers a 0.500mm x 0.375mm area at the film plane. Since this entire area is scanned 60 times per second, a flicker-free view of the magnified image of each taret as it is scanned can be displayed on the TV monitor included in the system.

The X-Y stage of the PASS 2000 moves the photo to such a position that the image of each target successively falls within the field of view of the CCD camera. The target image need not be centered in this field, therefore, accuracy of stage positioning is not necessary; just a high-

resolution, repeatable readout of where the stage is. However, since the PASS 2000 stage possesses one-micron linear encoders, one-count repeatability, and one-micron positioning ability, the excess positional error budget (field of view minus target image size) can be used to automate scanner operation as described below.

The approximate location of each target photoimage must be predetermined so that the X, Y stage can be driven to this position for the final, precise determination of the centroid coordinates. With the large error budget available when using the PASS 2000, these positions can be rapidly obtained with a manual digitizing tablet or equivalent low-accuracy device. A feature of this instrument is that only the first two photos in a set have to have their target coordinates predetermined. After the machine makes a precise determination of the centroid coordinates of all target images on the first pair of photos, it calculates the approximate image positions on the next succeeding photo in the set. This process continues for every photo in the set, automatically positioning the X-Y stage and determining target image centroid offsets relative to this position. Such fully-automated operation will increase the thruput time to as much as ten seconds per target, depending upon the exact operating scenario used.

PERKIN-ELMER

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PDS MODEL 2020GA/2020GM
MICRODENSITOMETER

The Perkin-Elmer PDS Model 2020G Microdensitometer is a flatbed optical scanning digitizer. It operates as a transducer, changing spatially-distributed analog data, such as may be contained in a photographic record, into a formatted array of digital values stored on industry-compatible magnetic tape. This A-to-D conversion is accomplished as follows: The Photographic transparency is raster-scanned past the optical axis of the instrument in such a fashion that the entire area of interest is covered by the raster. A beam of light is projected through the photo, through a sample-defining aperture, and onto the face of a photomultiplier tube. At any given instant, the intensity of the light incident upon the PMT is proportional to the opacity of that area of the photo defined by the sampling aperture. Thus, by periodically sampling and digitizing the analog output of the PMT, a "numerical image" is formed of the optical density modulations of the photographic image. This "numerical image" of spatially-distributed values is encoded on magnetic tape to be used instead of the photograph as a representation of the phenomena originally recorded.

The specifications of the PDS 2020G state that the maximum area which can be scanned is that bounded by a square of 20" on a side. The X-axis, which is disposed from right to left relative to the machine operator, is considered to be the axis of scan, while the Y-axis (front to back) performs the stepover function of the raster-scan pattern. Maximum scanning velocity (X-axis) is 200mm per second, but due to the distance required to accelerate to and from this speed, maximum-velocity scanning is limited to 19" in this axis. Such a maximum-velocity scan can be accomplished in no more than 2.69 sec., including ramp-up and ramp-down.

The Y-axis movement, typically from 5 to 400μ between X-scans, is limited to a maximum velocity of 20mm per second. Y-axis movement is designed to take place concurrently with the X-axis ramp-down.

The PDS 2020G Microdensitometer is designed in such a fashion that the X- and Y-axes are decoupled from each other. In other words, the photograph carrier moves in the X-axis only, while the optical axis and all related components are moved in the Y-direction of travel. This was done in order to minimize the mass of the high-velocity components and to increase the overall stability of the entire scanning system. The aforementioned reasons, as well as those of cost and of having a sufficiently massive base to resist the dynamic effects of stage acceleration, determined the ultimate configuration of the PDS 2020G. This machine is built upon a 52" X 54" X 10" granite surface plate, with granite rails bolted to it to establish each axis of stage travel. The rails are each located by precision spacers so that proper orientation of each may be maintained without recourse to expensive and time-consuming alignment procedures.

The X-carriage tracks between parallel pairs of rails located at the front of the machine. Adjustable side-guide bearings ensure that no lateral lost-motion exists throughout the entire 20" of stage travel. Adjustable support bearings provide low-friction movement in a plane parallel to the surface of the base plate. The carriage drive shaft and position-monitoring linear encoder are each located on the carriage centerline in plan view; drive mechanism on the left, and optical encoder on the right. The drive mechanism consists of an actuator which develops axial thrust through the action of spring-loaded rollers which are skewed relative to the axis of the smooth, unthreaded shaft they roll upon. Two actuators are provided with each microdensitometer; one enables a maximum stage velocity of 200mm per second, while the other limits the velocity to 50mm per second at the same maximum motor shaft speed. Two sets of adjustable overtravel switch actuators are provided to limit the distance traveled at high speed as well as the ultimate carriage excursion.

The PDS 2020G Y-carriage is supported and guided in a fashion similar to that of the X-carriage except that the rails run from front-to-back of the machine. Due to space restrictions, the Y drive is located atop the left-hand Y-rail, and the Y-encoder is mounted to the right. The X- and Y- encoders are identical, consisting of glass scales graduated at a spatial frequency of 125 line-pairs per mm. and encoder heads which put out signals which can be detected with a resolution of one count for every micron of carriage movement. The accuracy of these encoders is such that, taken conjointly with deviations in stage travel and the orthogonality of one carriage relative to the other, a Perkin-Elmer calibrated grid plate can be read whereby the grid intersections are located within $\pm$ 5μ of their true positions in each axis.

The Y-carriage of the PDS 2020G Microdensitometer consists of a C-shaped block of granite to which is mounted the Illuminator Assembly, Upper and Lower Microscope Assemblies, and the Upper Optical Assembly. The functions and controls associated with each Assembly are identical with those of the PDS Model 1010A Microdensitometer. Since the 2020G Y-carriage is driven no faster than 20mm per second, only one set of overtravel switch actuators is provided.

The Control Console for the 2020G is hinged to the right-hand side of the Microdensitometer supporting structure. Again, the controls are identical with those of the 1010A machine, but the entire Console may be pivoted in plan to a position confortable to the machine operator. When so located, the Console can be locked in place to prevent further movement.

The PDS Model 2020GA Microdensitometer has been designed to be directly interfaced to a 16-bit minicomputer which would then serve as the microdensitometer controller. In this configuration, the maximum digitizing rate is limited to 25,000 samples per second.

The PDS Model 2020GM Microdensitometer, on the other hand, has its own internal microprocessor controller. Therefore, it can operate in a

stand-alone mode if connected to a keyboard terminal and a magtape transport. An optional computer interface is available for data transfer to a 16-or 32-bit host. The digitizing rate of the PDS 2020GM is 50,000 samples per second.

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PDS MODEL 2020G
SPECIFICATIONS

STAGE

Travel, each axis	20 inches
Maximum Velocity, X Axis	200mm/sec.
Maximum Velocity, Y Axis	20 mm/sec.
Positional Accuracy, both axes	±5μ
Repeatability, each axis	±1μ
Resolution, each axis	1μ
Platen Rotation	±2°

PIXEL SIZES - Fixed Increments

5μ to 50μ square
5μ to 20μ diameter
2.5μ to 50μ wide X 50μ to 400μ long

PHOTOMETER	DENSITY	TRANSMITTANCE
Sensitivity[1]	0 to 4D	0 to 100%
Linearity[1]	±0.02D	±0.50%
Stability[1] [2]	±0.02D	±1%
Digital Resolution	0.01D	0.2% Maximum
Frequency Response[3]	3125 Hz[5]	(5)
Max. Sampling Rate	(6), (7)	(6)
Spectral Response	Bialkali	Bialkali
Noise-in-Signal[8]	(9)	

1 - With 10μ x 10μ picture element

2 - After 1 hour warmup

3 - At 8 samples per cycle

4 - From 0 to 2.5D

5 - 3125 Hz (2020GA); 6250 Hz (2020GM)

6 - 25,000/sec.(2020GA); 50,000/sec. (2020GM)

7 - Limited by Density Range

8 - Std. deviation of 100,000 samples

9 - 0.0025 X Density + 0.004

PDS MICRODENSITOMETER

ENVIRONMENTAL CONDITIONS

The PDS Microdensitometer is designed to operate in a "laboratory environment" of 70 degrees F. and 50% RH, with a minimum of excursion from nominal for each parameter. Since the instrument is manufactured from materials with uncompensated coefficients of thermal expansion, mechanical stability is a function of the thermal gradients across the instrument. Hot or cold air blowing on the Microdensitometer will make the various components move relative to each other, causing irrecoverable positional errors. Another possible source of error is excessive vibrations, either air-borne or transmitted through the floor. While three separate vibration-isolation systems are employed to cover a broad spectrum of frequencies, excessive amplitudes can still affect the instrument.

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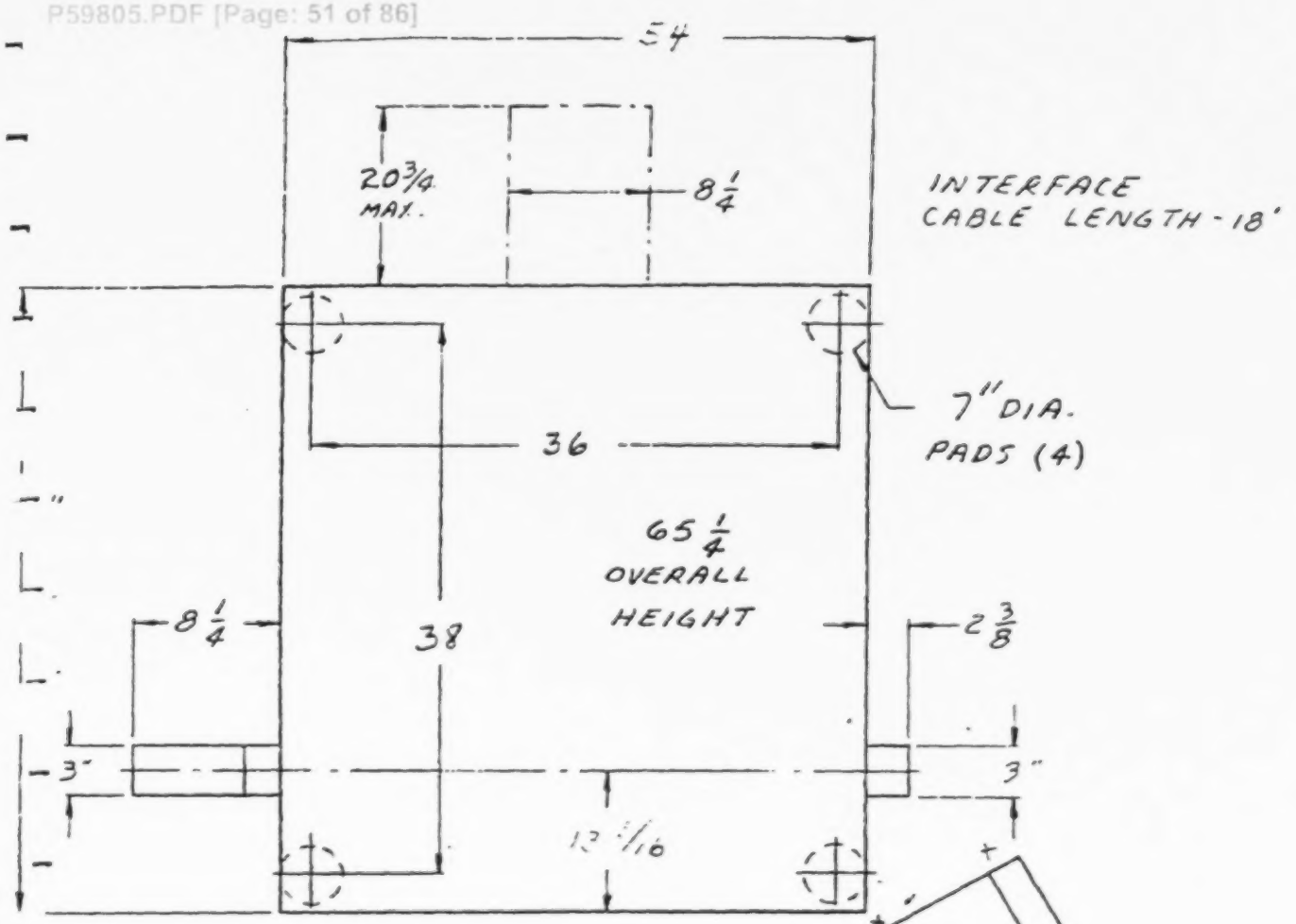
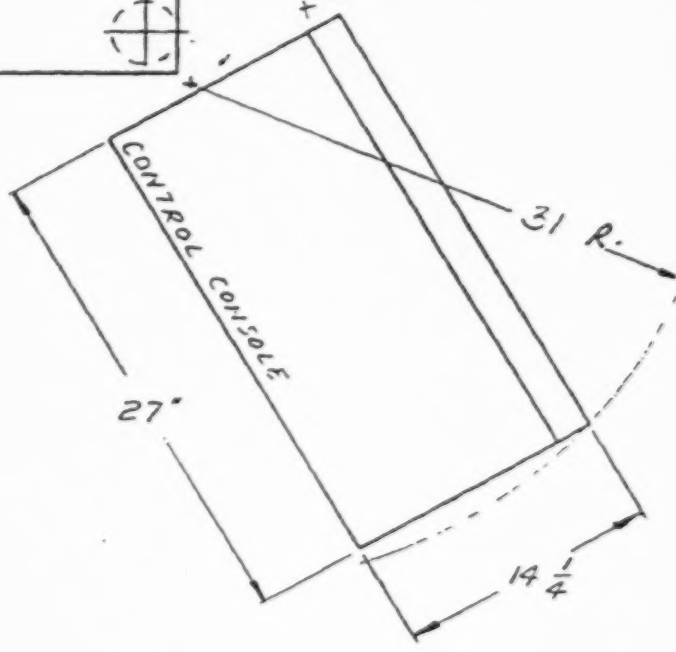


WT. 5200 LB.



PLAN VIEW

5 V 50/60 Hz 10 AMP.

POS MODEL 2020G MICRODENSITOMETER

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PHOTOGRAMMETRIC TRIANGULATION

Basic Concepts

A camera is similar to a transit or theodolite in that it allows one to determine the equivalent of horizontal and vertical angles to specific points of interest. The camera, however, differs from its counterparts in two important respects (refer to Figure 1). First, from any given instrument location (i.e. exposure station) directions to all points of interest are recorded simultaneously with a single "click" of the shutter. Second, these directions are calculated in the laboratory-totally removed from the environment of the job-site.

The determination of directions can be visualized by again referring to Figure 1. The location (x_p, y_p) of the image of a point of interest is measured on a photograph with the aid of a precise measuring instrument. The focal length (f) of the camera is known by laboratory calibration. These known values allow calculation of the direction to a point of interest on an object. This is accomplished mathematically by projecting a line from the exposure station through the photographic image of the point to the object. This direction is relative to the camera axis. However, if we assume that the direction of the camera axis is known in the object coordinate system, then the absolute direction to the point of interest can be determined. When two or more absolute directions to the same point of interest are known, they intersect in three dimensions to yield the coordinates (X_p, Y_p, Z_p) of that point of interest.

Targeting

Photogrammetric triangulation is utilized when coordinate measurements of specific points of interest are required. Since two or more photographs are taken of the object from different locations, it is necessary that the same points of interest be measured on all photographs. This is facilitated by the use of targets placed on the object thereby eliminating subjective decisions as to the locations of these points on the photographs.

Targeting (Cont.)

Precise positioning is seldom required in the placement of targets on the object being measured. However, different targeting situations must be considered. On the one hand, statistical sampling of a surface may suffice, in which case targets are more or less randomly placed on the object as in Figure 1. On the other hand, there may be specific points on the object which must be uniquely defined. In such a case more care is required in the placement of targets.

Convergent Photographs

Calculation of the X_p, Y_p, Z_p coordinates of a target is accomplished by intersecting two or more lines to the target as indicated in Figure 1. If the lines were to approach parallelism with one another, the determination of their intersection would become less precise. Conversely, as the lines intersect at greater included angles, the location of their intersection becomes easier to pinpoint.

To achieve optimum angles of intersection it is necessary to take photographs that have the camera axes steeply inclined relative to one another yet still pointed toward the object. Photographs taken in this manner are said to be convergent. This is in contrast to the usual case of stereo photogrammetry where the camera axes are made nominally parallel.

Multiple Photographs

As mentioned above, more than two lines can be mathematically intersected at a given point of interest. Therefore, more than two photographs can be taken, measured, and introduced into a computer program: the larger number of intersecting lines again increasing the accuracy of the intersection. These additional photographs are usually taken from different exposure stations. This can be visualized in Figure 1 if one were to imagine a third photograph behind the plane of the sketch and a fourth in front.

Mathematical Basis

Again using Figure 1 as a reference, measurements (x_p, y_p) of target images on the photographs constitute the photogrammetric "observations" (similar to observing horizontal and vertical angles with a theodolite or transit). These observations are related to the exposure station location X_L, Y_L, Z_L; the orientation of the camera axis represented by three rotations (ω, ϕ, κ) about the photographic coordinate system axes; and the location of the target X_p, Y_p, Z_p. In functional form these relations are expressed as:

$$\begin{bmatrix} x_p \\ y_p \end{bmatrix} = f\,[X_L, Y_L, Z_L, \omega, \phi, \kappa, X_p, Y_p, Z_p\,]$$

This equation states that the exposure station, the target, and its image all lie on the same straight line.

Camera Locations

We had assumed earlier that the locations of the exposure stations and the directions of the camera axes were known in advance, but this need not be so. For each image measured on a photograph, a pair of "observation equations" of the functional form given above is generated in a computer program. Each equation pair contains two measured values to the left of the equal sign and 9 unknown values to the right. But when all such equations are generated there are more observed values than unknowns and the system is, therefore, overdetermined and may be solved by the method of "least squares".

To illustrate this point, assume that four photographs have been taken of a targeted object. Also assume there are 300 targets on the object and that all targets are imaged on all photographs. For observed values we will have 2,400 photographic measurements x_p, y_p (2 measurements per

Camera Locations (Cont.)

image x 300 images per photograph x 4 photographs). For unknowns we will have the 24 locations of the exposure stations and directions of the camera axes (3 coordinates and 3 directions per photograph x 4 photographs) plus the 900 unknown target coordinates (3 coordinates per target x 300 targets). There will be a total of 2,400 equations containing 924 unknowns: a system over-determined by a factor of 2.6.

Even though we are mostly interested in calculating the X_p, Y_p, Z_p coordinates of each target, we also calculate the locations of the exposure stations and the directions of the camera axes at the same time. Therefore, it is unnecessary to pre-survey exposure station locations or to pre-determine camera pointing directions except to obtain the desired photographic coverage.

Establishing True Scale

Since the exposure station locations are not pre-surveyed, the solution described above cannot be performed at exact true scale. Instead, it is solved at an approximate scale by estimating the exposure station locations. Afterwards, the computed target coordinates X_p, Y_p, Z_p will be rescaled by that factor which brings the approximate scale to true scale.

To determine this scale factor distances between several pairs of targets on the object are physically measured. Corresponding distances are computed from coordinates of the same targets as determined in the approximately-scaled photogrammetric solution. The ratio of measured distance divided by calculated distance gives the scale factor for that target-pair. The average scale factor over all measured target pairs is used to bring the approximate solution to true scale.

Error Analysis

As mentioned above, the entire system of photogrammetric equations is solved according to the method of "least squares". Such a solution produces only one answer, with standard deviations of all computed values being obtained as a by-product. If it is assumed that all errors are randomly distributed, the method of least squares produces the answer of "maximum likelihood" according to statistical theory.

Measurement Residuals

The location of a point in space can be determined by intersecting two non-parallel lines. Since more than two photographs are usually taken there may be more than two lines intersecting such a point. In the least squares solution a single set of X_p, Y_p, Z_p coordinates is determined for the point and these coordinates are those that best fit all incoming lines. Therefore, there is only one set of coordinates for that point.

All lines usually do not exactly intersect at the computed X_p, Y_p, Z_p coordinates of a point. Therefore a line is projected back to each photograph from the computed location of each object point to obtain computed locations of the images of the point on all photographs. These computed image locations are compared with the measured locations (i.e. the x_p, y_p of Figure 1) to provide "measurement residuals". If the photographs were accurately measured, these residuals will typically be less than 3 micrometers (0.00012 inch) with a standard deviation of 1 to 1.5 micrometers (0.00004 to 0.00006 inch).

Standard Deviations

Standard deviations of computed X_p, Y_p, Z_p coordinates are obtained from the least squares solution. Every coordinate will have a unique standard deviation because it is a function of the number of lines intersecting a point, the lack of intersection of all lines (manifested in the measurement residuals), the geometry (included angles of intersection) of the

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Standard Deviation (Cont.)

incoming lines, the focal length of the camera, and the distances from the camera stations to the point. All of these factors are taken into account in the standard deviations.

Fit to Reference Distances

Another measure of the quality of the photogrammetric solution is the "fit" to the scale reference distances mentioned above. After scaling the photogrammetric solution by the average scale factor, each scale reference distance may be recomputed using the scaled photogrammetric coordinates X_p, Y_p, Z_p. These computed distances can then be compared to the measured values.

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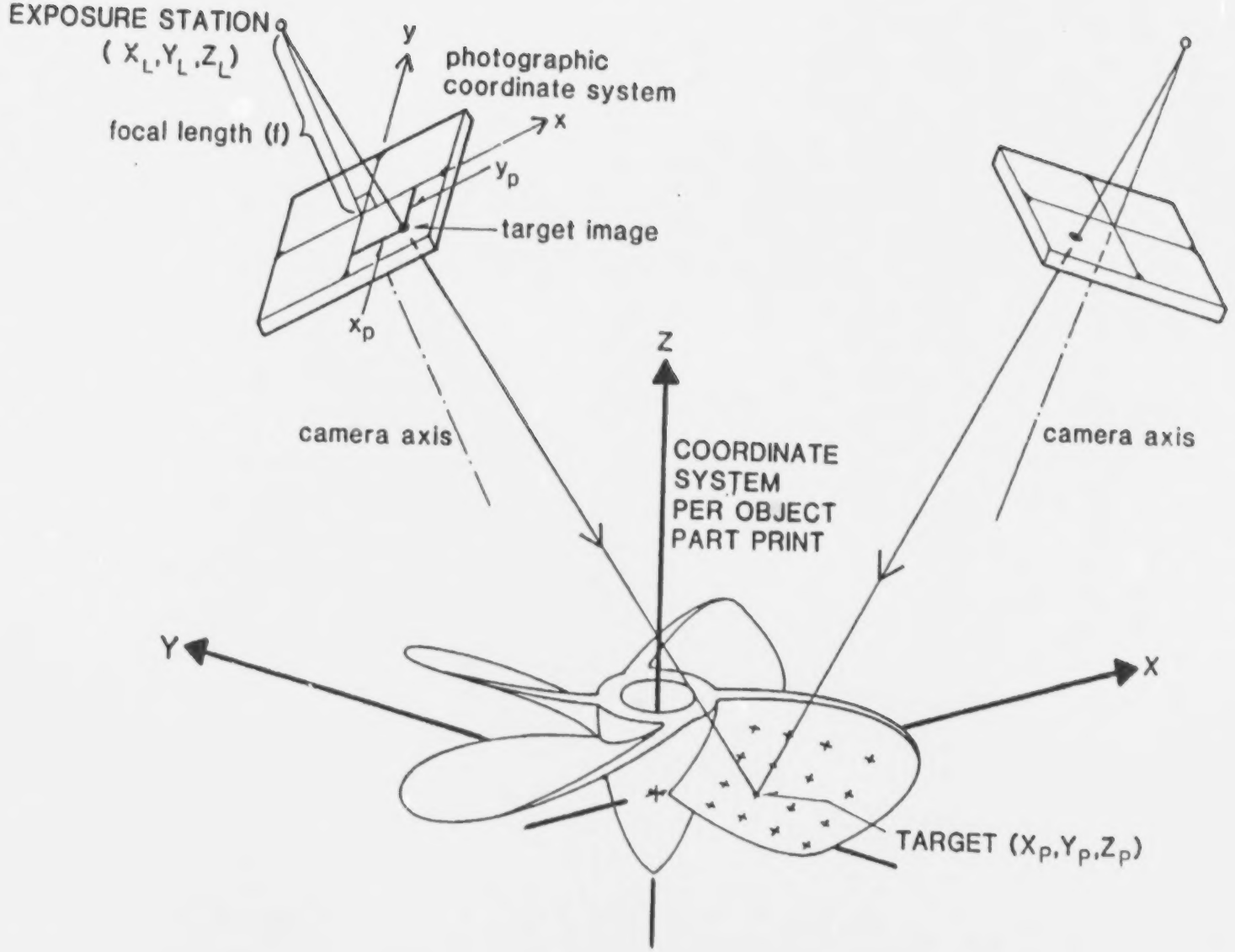

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a technical presentation of the PDS Microdensitometer

FIGURE 1

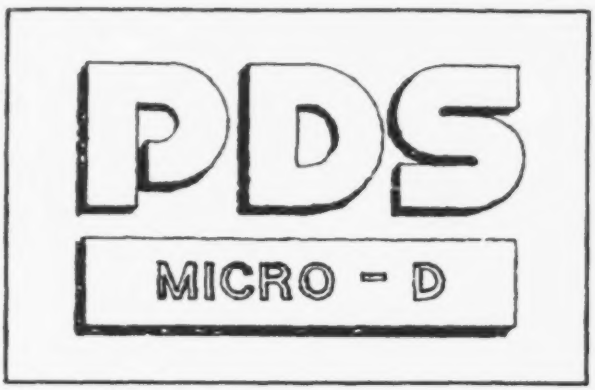

FIGURE 2

PERKIN-ELMER

Page 3	PERKIN-ELMER AOD
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Page 21	SPECIFICATIONS
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Page 31	OPERATION
Page 35	CONFIGURATION

Welcome to this presentation of the Perkin-Elmer PDS Micro-D, recognized throughout the world as the standard by which all other photodigitizing instrumentation is judged.

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PERKIN-ELMER AOD

FIGURE 3

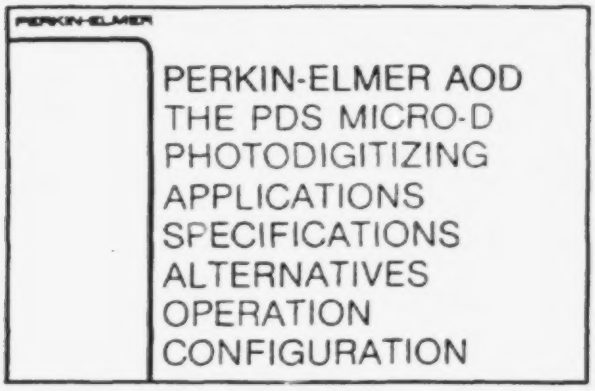
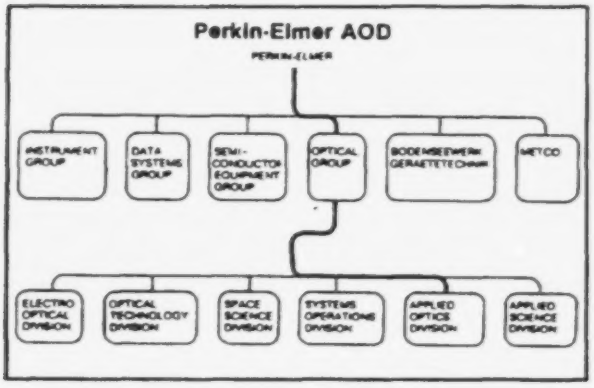
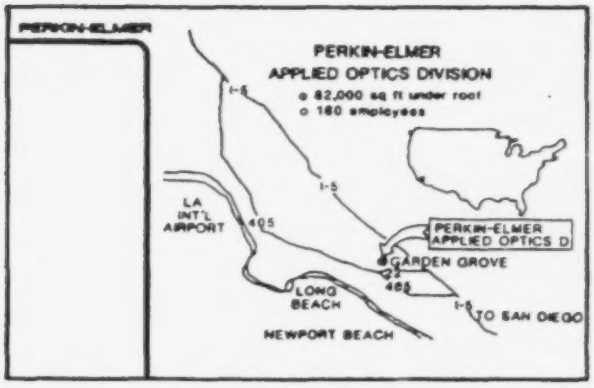


FIGURE 4



The Applied Optics Division is a member of Optical Group, one of six major operating subdivisions of tl Perkin-Elmer Corporation

FIGURE 5



This division is located in Garden Grove, near Los Angeles in Southern California.

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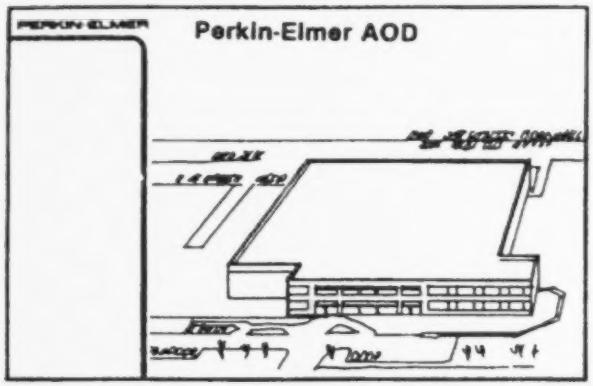
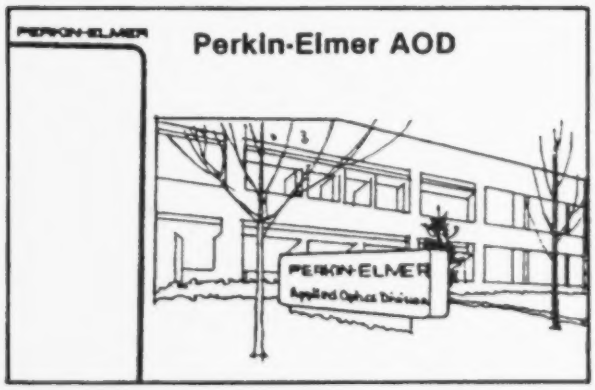
FIGURE 6



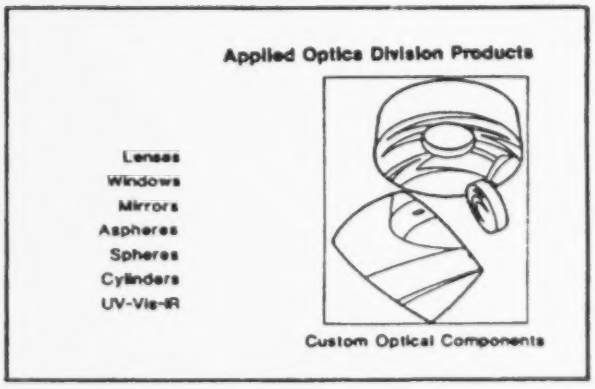
The 82,000-square foot facility was built in 1981. It is occupied solely by the Applied Optics Division.

FIGURE 7



The division employs more than 180 people and has complete fabrication and assembly facilities for its various product lines.

FIGURE 8



These include custom optical components . . .

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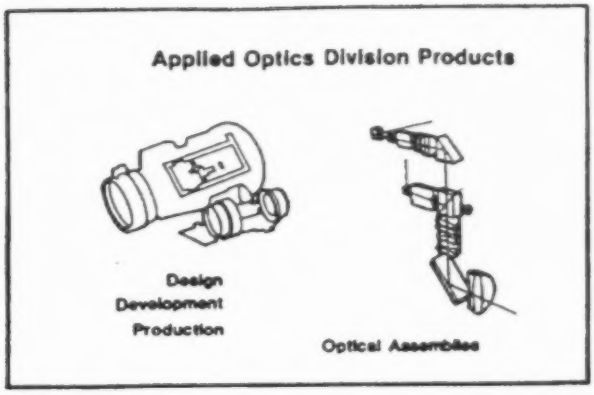
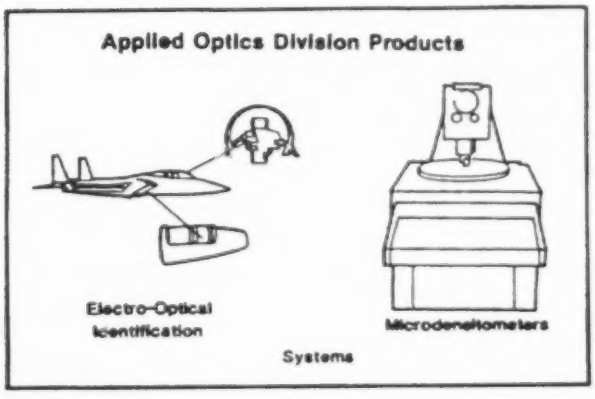
FIGURE 9



. . . optical assemblies . . .

FIGURE 10



. . . and optomechanical systems.

THE PDS MICRO-D

FIGURE 11

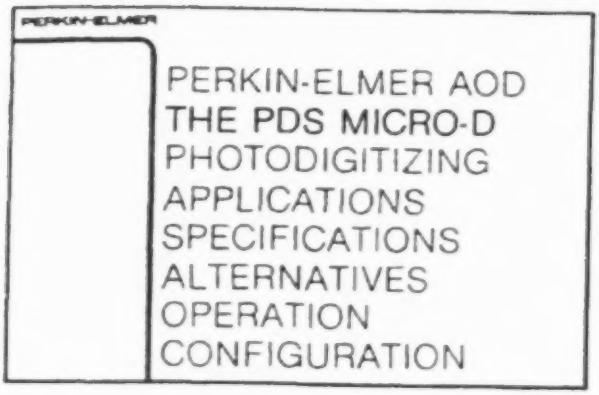
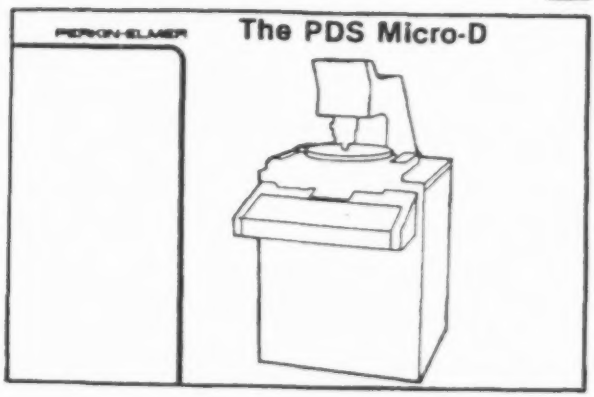
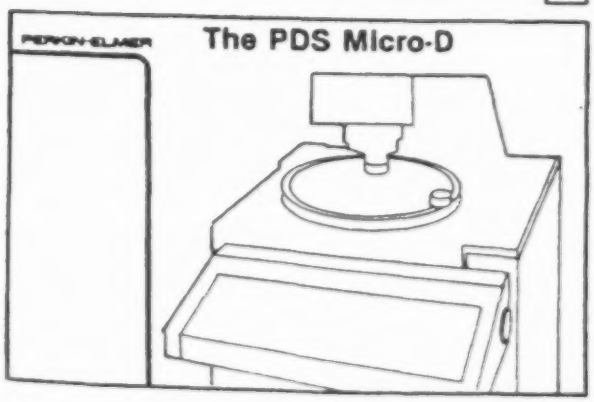


FIGURE 12



The PDS Micro-D is a self-contained, free-standing flatbed scanning photodigitizer. It occupies less than 3 feet of floor space, yet is so ruggedly built that it weighs 750 pounds. The massive overarm is an integral part of the stage support structure, ensuring the rigidity needed for highly-accurate scanning performance. Power requirements for this instrument are: 115 volts, 50 or 60 Hertz, 10 amps.

FIGURE 13



The stage can scan 10 inches, or 254 millimeters, in each axis. The specimen platen is fully rotatable with a manual drive knob to facilitate fine angular positioning. The stage is motor-driven through zero-backlash actuators and its position is constantly monitored by linear optical encoders for each axis. All controls are readily accessible to the operator, including those for such functions as aperture and filter change, magnification change and focus, photometer calibration, and manually-controlled stage drive. Stage position and sample density readouts are centrally located.

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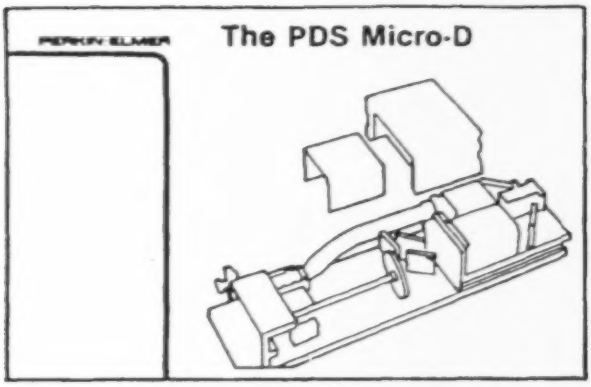
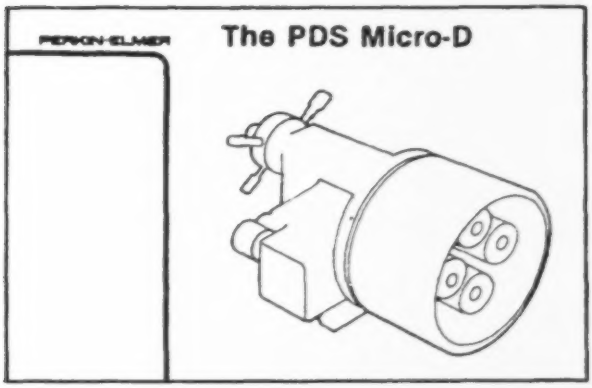
FIGURE 14



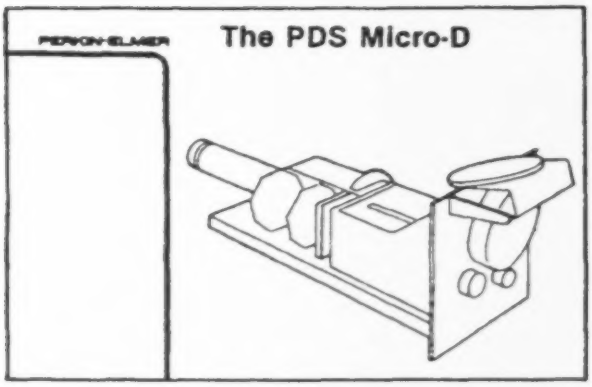
The illuminator assembly is a slide-out drawer containing the light source, optics, and source aperture disc. In addition, there is a fiber optic bundle which can be conveniently moved into place by the machine operator to provide illumination which will fill the microscope field of view. This allows the operator to see that area of the specimen which is viewed by the microscope.

FIGURE 15



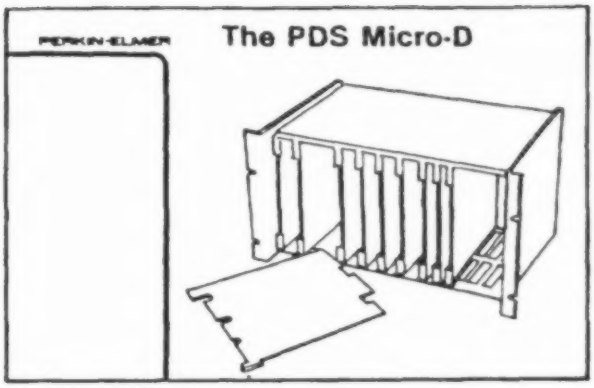
The upper microscope assembly carries four turret-mounted eyepieces, can be manually focused, and has a quick-disconnect centering nosepiece for the single objective. The lower microscope assembly is similar except for the centering nosepiece.

FIGURE 16



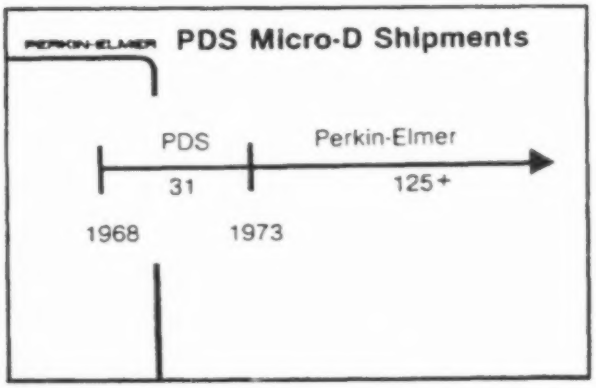
The photometer assembly is a slide-out drawer containing the photosensor, an on-line viewing screen, and color filter, N.D. filter, and scanning aperture discs.

FIGURE 17



The PDS Micro-D has an on-board microprocessor to automatically control the scanning and digitizing functions associated with photodigitizing a specimen including storage of the digital output on magnetic tape.

FIGURE 18



A great number of PDS Micro-D's have been sold by Perkin-Elmer since the acquisition of this product line in 1973. These instruments are all characterized by long life and trouble-free operation.

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PHOTODIGITIZING

FIGURE 19

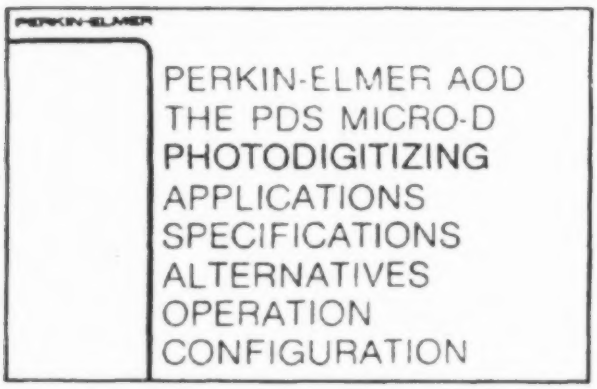
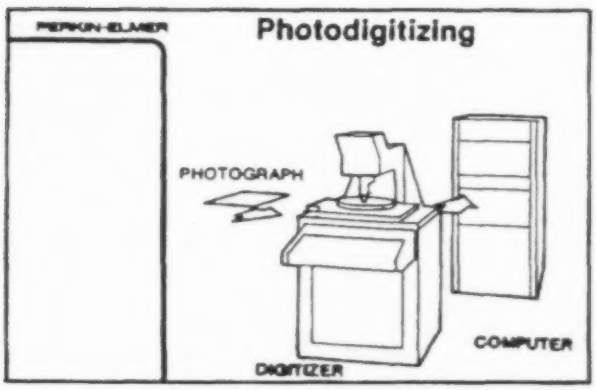
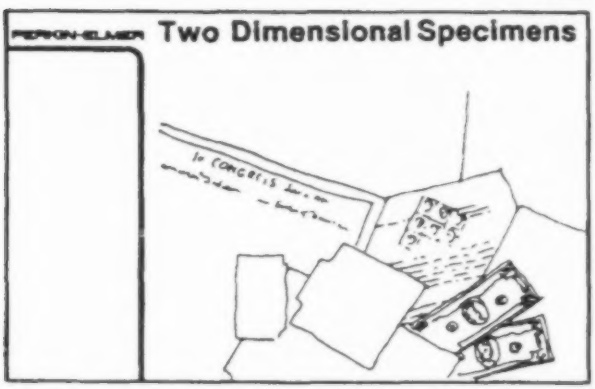


FIGURE 20



Photodigitizing is the extraction and digitization of spatially-distributed visual data from two-dimensiona specimens. In other words, it is the conversion of continuous tone imagery into a computer-compatibl format.

FIGURE 21



Two-dimensional specimens are usually photograph of real-world features or events. However, any specimen, as long as it is sufficiently photograph-like, can be photodigitized. For instance, Xerox copies, PC boards, IC masks, tissue samples, paper maps, money, and postage stamps are all examples of two-dimensional specimens.

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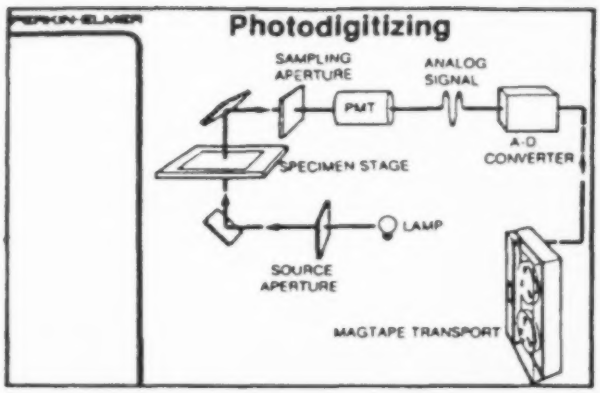
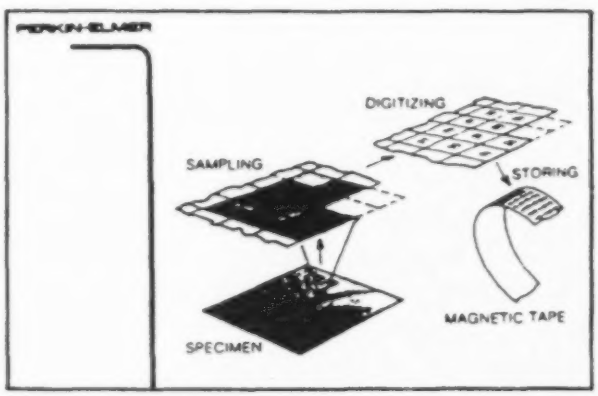
FIGURE 22



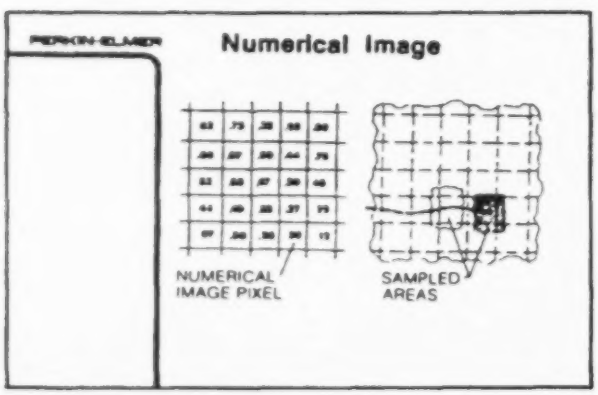
The specimen is scanned past the optical axis of a photodigitizer so that the entire area of interest is covered. A beam of light projected through the specimen passes through a sample-defining aperture and falls on the face of a photomultiplier tube. At any given instant, the intensity of the light falling upon the PMT is inversely proportional to the opacity of that area of the specimen defined by the sampling aperture. The analog output of the PMT is periodically sampled, digitized, and encoded on magnetic tape for storage or subsequent manipulation in a computer.

FIGURE 23



Such scanning and digitizing divides the specimen into a two-dimensional array of picture elements or pixels. Each pixel is assigned a numerical value proportional to the amount of light passing through the sampled area. A numerical image is thereby created, with spatially-distributed numbers representing the specimen scanned.

FIGURE 24



The numerical image, being a mathematical construction, is composed of pixels that are perfectly arranged and of uniform size. The pattern of sampled areas, however, is generated by the photodigitizer and is therefore subject to errors of size and placement as well as those of photometric measurement.

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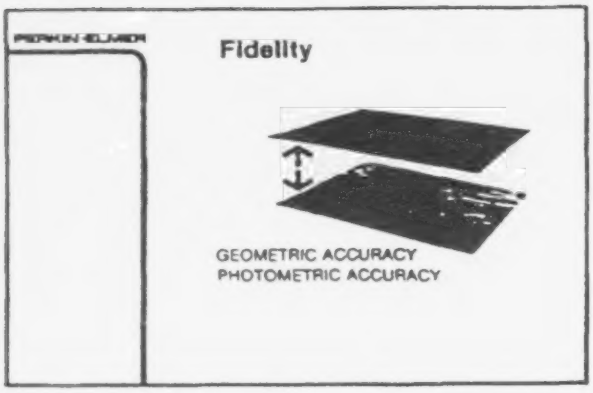
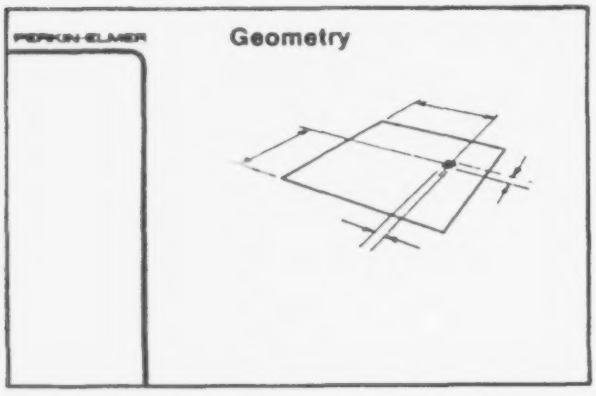
FIGURE 25



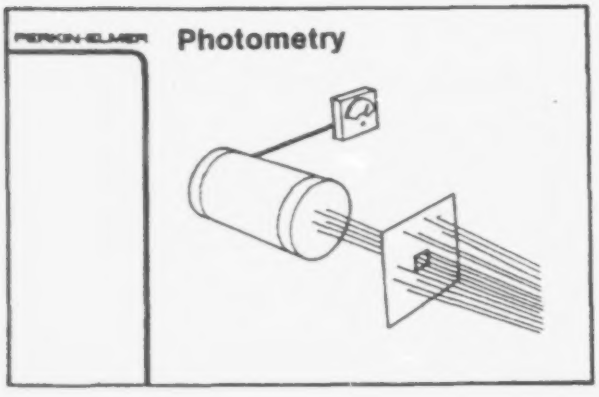
In this context, fidelity can be defined as how well the numerical image represents the sampled specimen. It is, therefore, a measure of photodigitiz performance. High fidelity in a photodigitizer requir both geometric and photometric accuracy.

FIGURE 26



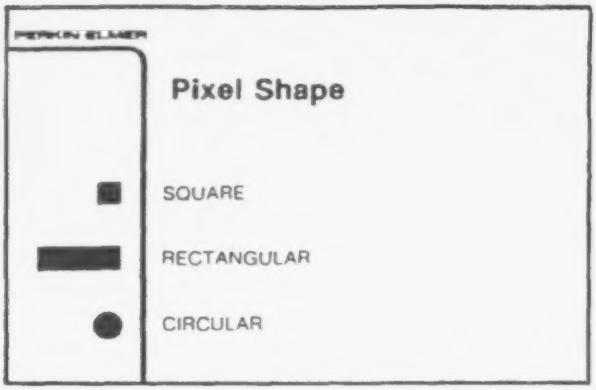
Geometry refers to the sampled area size and location. They must match the numerical image pixels as closely as possible.

FIGURE 27



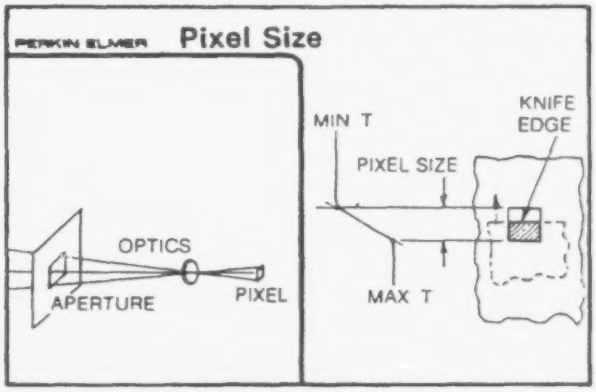
Photometry refers to the measurement of photon fl through the sampling aperture. It must agree with the actual opacity of the sampled area on the specimen.

FIGURE 28



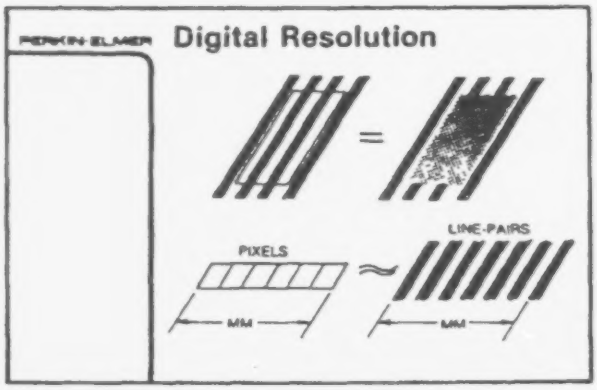
The choice of sampling aperture shape depends upon the particular photodigitizing application involved. A square is the optimum shape for covering a two-dimensional area. There are no gaps, and equal resolution is obtained in each axis. Rectangular apertures are used where the informational content of a specimen lies in one dimension only, as in spectrographic lines and knife edges. The advantage of the slit aperture in such a case is that high resolution can be obtained in the axis of interest while more light can be passed through the system, reducing noise. Circular apertures are used mostly for granularity studies and for statistical analyses.

FIGURE 29



The nominal size of the area being sampled can be obtained by dividing the nominal aperture size by the nominal optical magnification ratio. However, due to the many variables involved, a more accurate determination can be made by means of the technique shown. A knife-edge is scanned using the aperture in question. The slope of the transmittance response is projected to the maximum and minimum amplitudes. The lateral distance between the intercepts is the true effective aperture size.

FIGURE 30



In a photodigitizer, the photon flux is integrated over the entire sampling aperture; there is no sub-pixel modulation in the numerical image. Therefore, the spatial resolution of a numerical image is solely a function of the pixel size. Photographic resolution, the smallest discernable separation of features in a photoimage, is measured at the limit of human vision, approximately 4 percent contrast. The relation between photographic and digital resolutions is that digital resolution, in pixels per millimeter, approximately equals photographic resolution in line-pairs per millimeter. In other words, digitizing with a 25-micron pixel will give results roughly equivalent to 40 line-pair photographic resolution.

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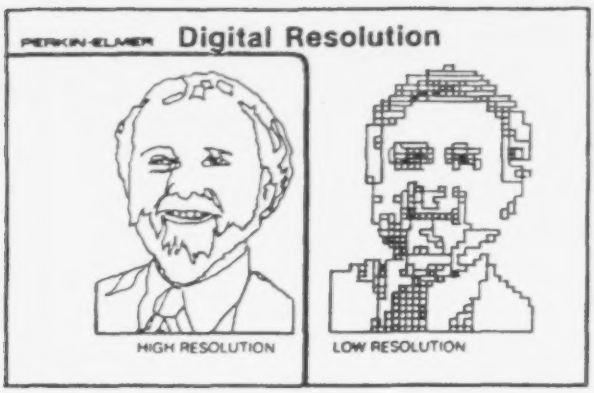
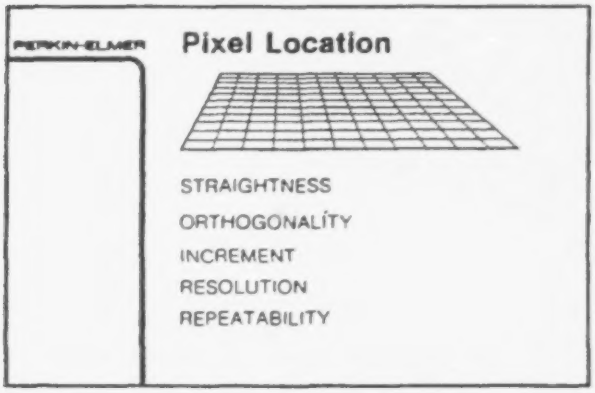
FIGURE 31



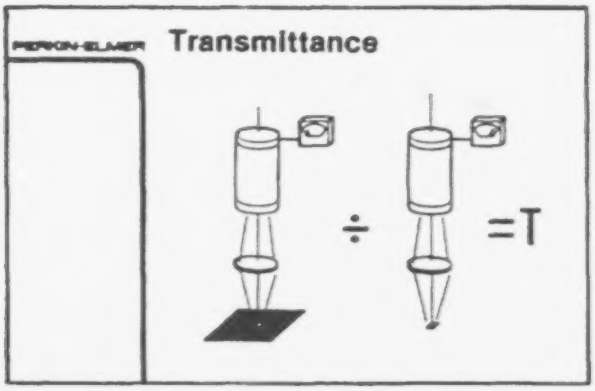
Examples of the results of both high- and low-resolution digitizing are shown here. Obviously, high resolution photodigitizing generates more data than low-resolution photodigitizing. This requires a longe scanning time and more data storage capacity. Therefore, to save time and money, always digitize with the largest pixel size suitable for the application.

FIGURE 32



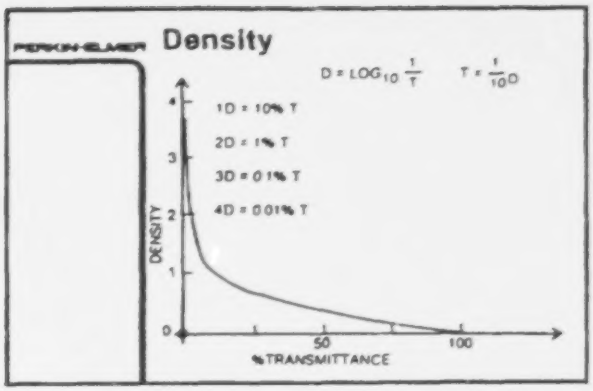
In order to assure the proper placement of the sampling aperture relative to the specimen, these conditions must be met: the specimen must be scanned along straight lines, the scan axes must be orthogonal, and the sampling increment must be matched to the actual sampling aperture size, requiring high resolution in the setting of this increment. Finally, all aspects of scanning motion and measurement must be highly repeatable.

FIGURE 33



Transmittance, "T", is the ratio of the photon flux through a sampled area of a specimen to the flux through the same area without the specimen in the optical path. It is the actual physical quantity measured by a photodigitizer.

FIGURE 34



Density is the logarithm of the reciprocal of transmittance. Density values correspond closely with the human eye's perception of levels of brightness. Expressing photometric values in terms of Density is also a convenient, shorthand way of dealing with the small Transmittance values associated with the darker areas on a photoimage.

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APPLICATIONS

FIGURE 35

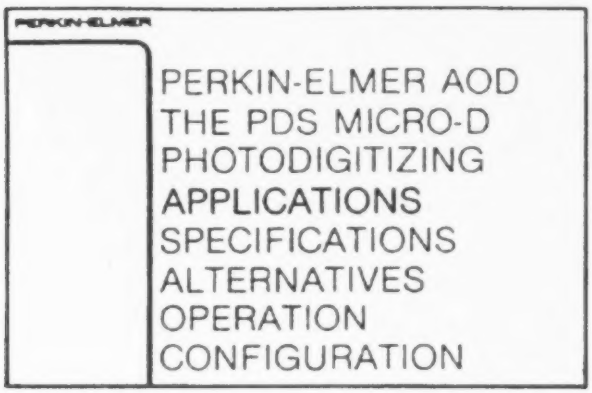
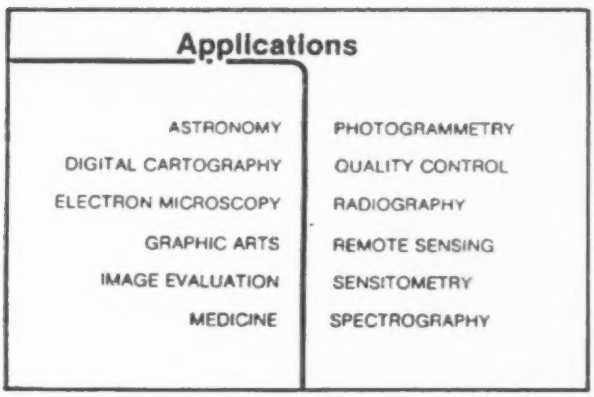
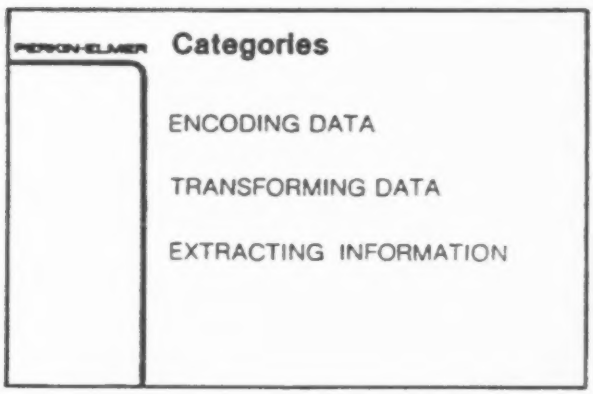


FIGURE 36



Photodigitizing finds application in many fields:

FIGURE 37



All such applications fall into one or more of these categories:

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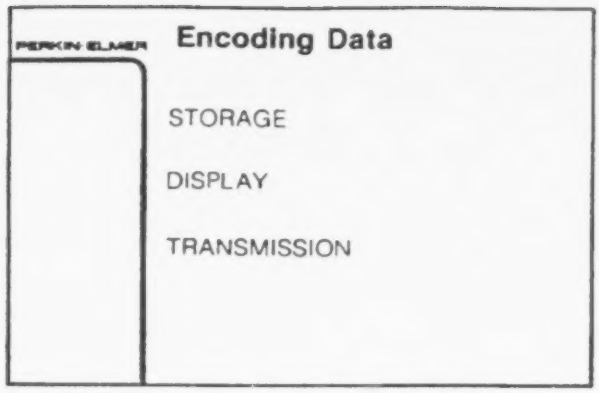
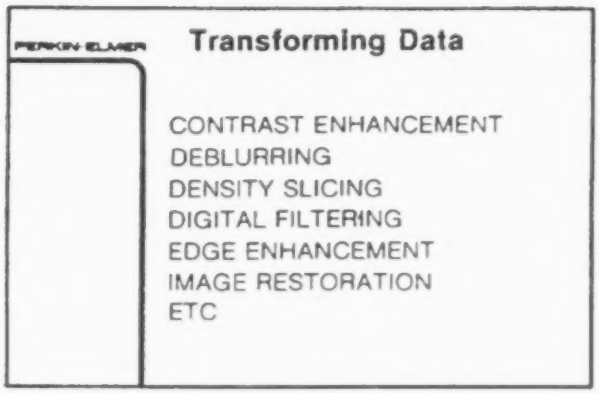
FIGURE 38



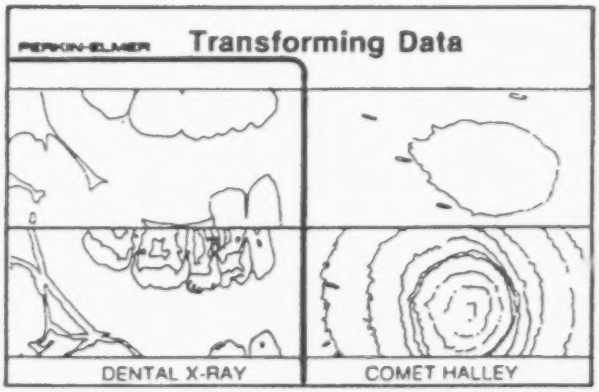
Data may be uncritically digitized . . .

FIGURE 39



. . . or the image of a two-dimensional specimen may be converted into a better-looking or more useful form by a number of image processing techniques.

FIGURE 40



The dental X-ray has been digitally enhanced by a process of high-pass filtering followed by a Density histogram equalization. The enhancement of the photograph of Comet Halley shows how areas of equal Density can be displayed.

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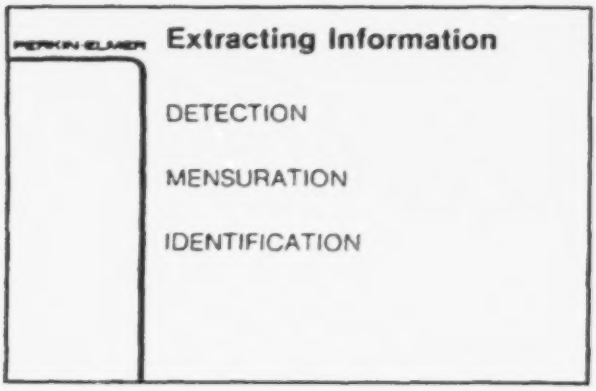
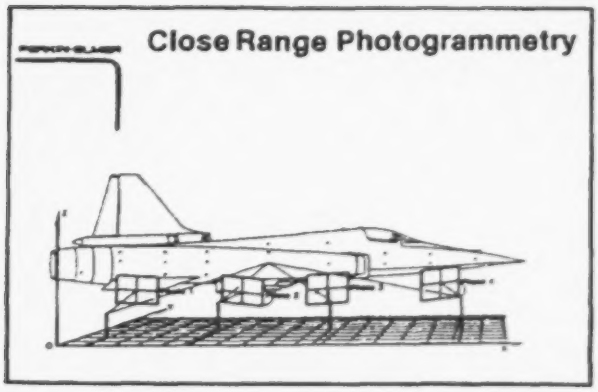
FIGURE 41



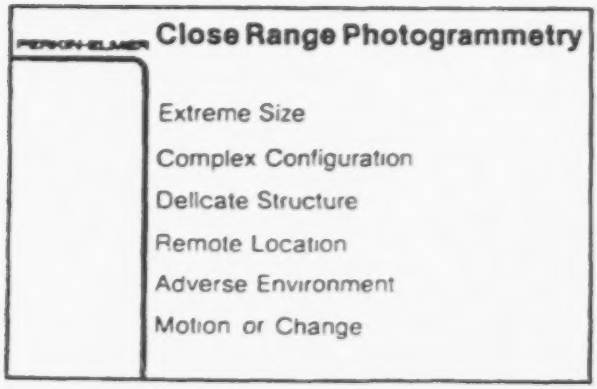
Information extraction can be sub-classified as the determination of the existence, size, shape, or location of a particular feature, or of the spatial relationships between such features. In addition, it can include the recognition of the photometric "signature" or particular pattern of Density variations associated with a feature.

FIGURE 42



Close-range photogrammetry is the technique of determining the dimensions of an object by measuring photographs of that object. Two or more overlapping photographs are needed for such a determination to be made. In order to positively identify the same object point on different photos, targets may be attached to, or projected on, the surface being inspected. X, Y, Z object coordinates are then obtained by triangulating the X, Y photo coordinates. Only one point per photo has been shown in the illustration for reasons of clarity.

FIGURE 43



Close-range photogrammetry is used in situations where the object to be measured is too large for conventional measuring techniques, or where configuration or structure makes direct measurement difficult. This technique is also useful where the object is either inaccessible or otherwise untouchable, or where the object would change in location or size while conventional measurements are being made

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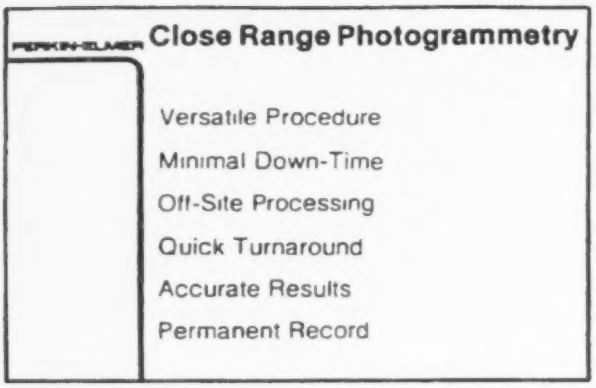
FIGURE 44



Of the many advantages to be gained by using close-range photogrammetry, the most useful is the accuracy which can be obtained. The location of a targeted point can be determined to within one-one hundred thousandth of the distance from the camera to the object

SPECIFICATIONS

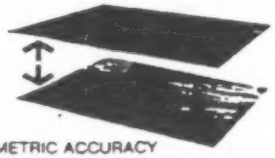
FIGURE 45

PERKIN-ELMER

PERKIN-ELMER AOD
THE PDS MICRO-D
PHOTODIGITIZING
APPLICATIONS
SPECIFICATIONS
ALTERNATIVES
OPERATION
CONFIGURATION

FIGURE 46

PERKIN-ELMER **Requirements for Fidelity**



GEOMETRIC ACCURACY
PHOTOMETRIC ACCURACY

The performance of a photodigitizer has been equated with the fidelity of a numerical image relative to a sampled specimen. Both a correctly sized aperture, sampled at the proper location, and an accurate measurement of photon flux are needed. A review of the PDS Micro-D specifications will show how these are provided by this instrument.

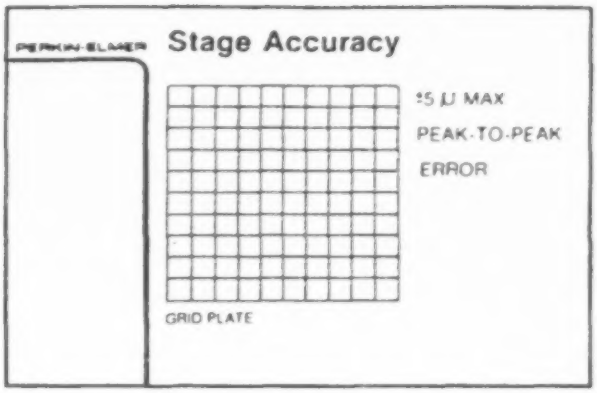
FIGURE 47

PERKIN-ELMER **Pixel Sizes**

	APERTURE - MM		PIXEL - μ	
	MIN	MAX	MIN	MAX
CIRCULAR	1	8	5	120
SQUARE	1	5	5	100
SLIT WIDTH	0 5	3	2 5	60
SLIT LENGTH	5	20	25	400

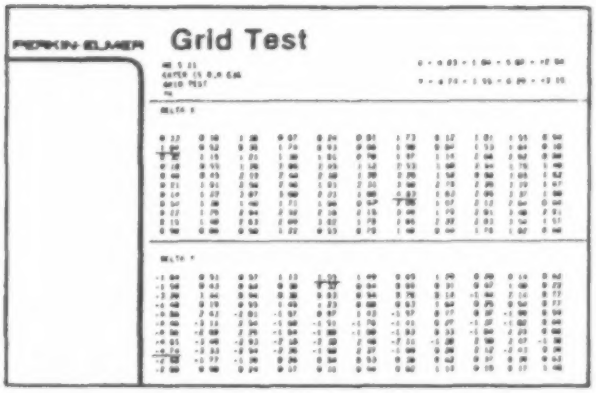
The PDS-Micro-D has 8 apertures mounted on a detented disc. With 4 optical magnifications available, 32 different pixel sizes are possible. Aperture sizes can be specified by the customer within the limits shown. Tabulated pixel sizes are based on optical magnifications of 200X and 50X

FIGURE 48



Stage accuracy is verified by scanning a calibrated grid plate and comparing measured intersection locations with their known values. Errors measured in this way are a composite of travel straightness and orthogonality, and encoder accuracy. These errors will be no more than plus or minus 5 microns peak-to-peak in each axis.

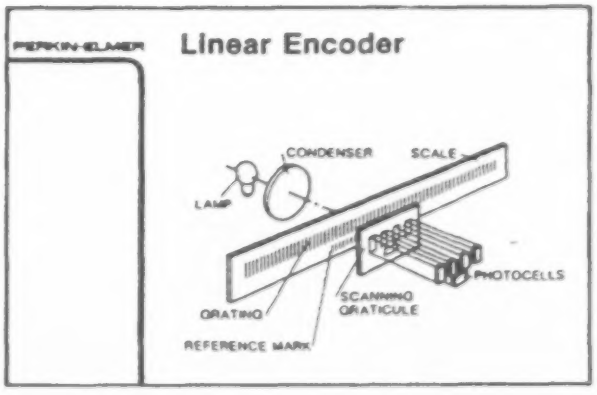
FIGURE 49



This typical grid test printout shows that most of the errors are quite small.

For this test, the standard deviation of errors in the X-axis is 1.02 microns. In the Y-axis it is 1.47 microns. Repeatability is specified as being plus or minus 1 micron in each axis.

FIGURE 50



A linear optical encoder monitors each axis of stage motion with zero backlash. The scale grating has 125 line-pairs per millimeter. The graticle contains two sets of similar gratings, with a 90-degree phase offset between them. This allows the encoder to sense the direction of scan

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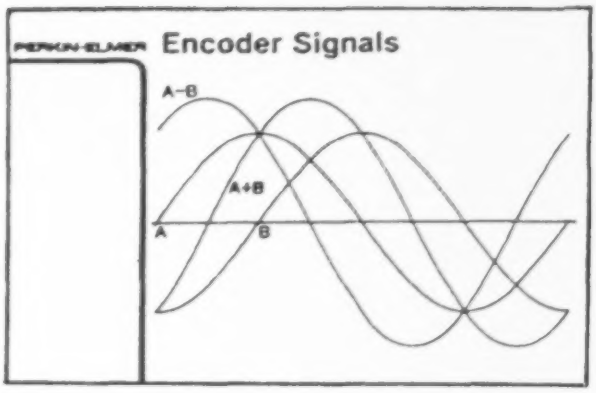
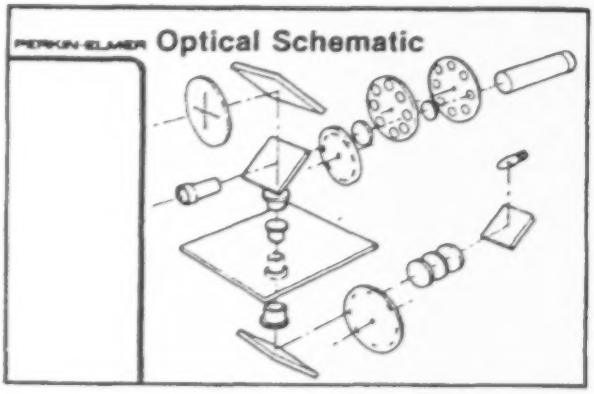
FIGURE 51



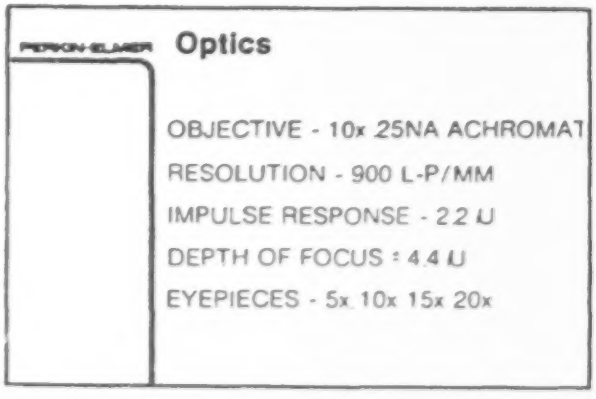
The two channels of sinusoidal encoder signals are combined as illustrated This technique gives 8 zero-crossings per cycle, or one output pulse for each micron of stage movement. The sampling increment can thus be set to any integer micron value, allowing a near-perfect match with the actual sampling aperture size

FIGURE 52



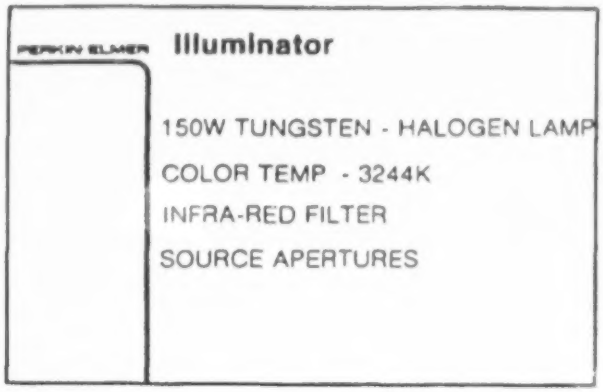
This schematic shows the relative positions of all the optical components involved in the photometric measurement of a specimen. Each major group of components will be treated separately

FIGURE 53


PERKIN-ELMER
Optics
OBJECTIVE - 10x .25NA ACHROMAT
RESOLUTION - 900 L-P/MM
IMPULSE RESPONSE - 2.2 U
DEPTH OF FOCUS = 4.4 U
EYEPIECES - 5x 10x 15x 20x

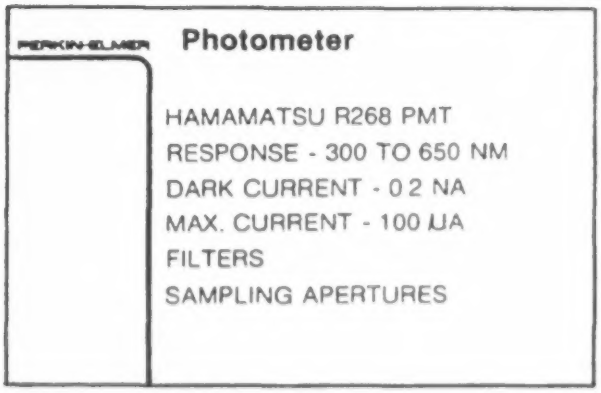
Symmetrical compound microscopes are provided for influx and efflux optics. Other configurations can be provided if desired. Overall nominal magnification ratios of 50X, 100X, 150X, and 200X are provided unless otherwise specified.

FIGURE 54



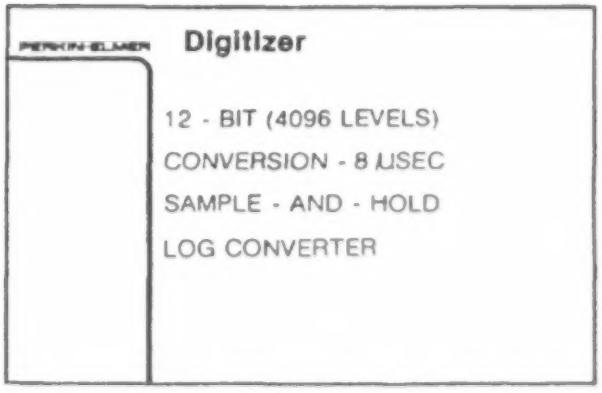
The illuminator assembly is the source of the photon flux which is measured by the instrument. A broad-spectrum light source is used for optimum matching to the photosensor spectral response, and so that colored specimens can be digitized. Source apertures, slightly larger than the corresponding sensor apertures, are used to minimize the effects of flare light in the system.

FIGURE 55



The photosensor converts the photon flux into an electrical current and amplifies it to a useful level. There are more than five orders of magnitude between saturation and noise level, ensuring a high signal-to-noise ratio in the instrument. Red, green, and blue filters are provided for color-separation scanning, and seven Neutral-Density filters are used for internal calibration purposes.

FIGURE 56



An A-to-D converter changes the analog PMT signal into a digital format. A sample-and-hold amplifier restricts the change in signal during this conversion to less than half a microvolt. The logarithmic converter is used when output in Density units is desired. Its dynamic range is 0-to-4D and it has a log conformity specification of at least 99 percent. Frequency response in the Density mode is a function of the rate-of-change and amplitude of the Density difference.

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FIGURE 57

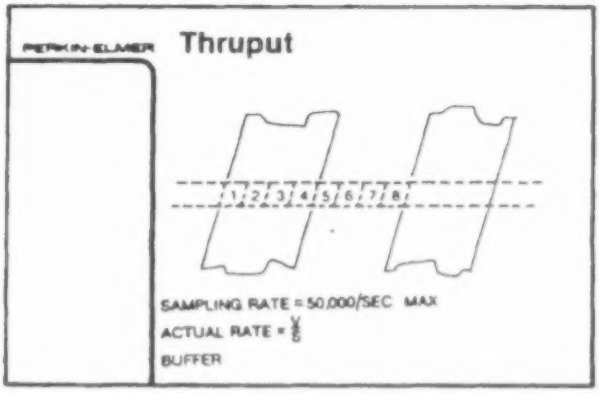
PERKIN ELMER **Performance**

	TRANSMITTANCE	DENSITY
LINEARITY (1)	±0.5%	±0.020
STABILITY (1)(2)	±1%	±0.020
DISPLAYED RESOLUTION	0.2% max	0.010
FREQUENCY RESPONSE (3)	6250 Hz	3128 Hz(4)

(1) USING 10 μ SQUARE PIXEL
(2) AFTER 1 HR WARMUP
(3) AT 8 SAMPLES PER CYCLE
(4) 0 TO 2.5D

The PDS Micro-D photometric performance fulfills the requirements for high-fidelity photodigitizing. In conjunction with the stage geometric accuracy, it characterizes the best photodigitizing instrumentation commercially available.

FIGURE 58



In order to properly digitize a square-wave feature on a specimen, such as a line or spot, it is recommended that no less than eight samples be taken for each cycle of such a feature. In other words, the sampling aperture should be no more than one-quarter the line or spot width. The actual rate at which samples are taken equals the scan velocity divided by the sampling increment. For example, scanning at 50 millimeters per second with a 10-micron increment results in a rate of 5000 samples per second. The number of samples which can be acquired per scan line varies between 3,200 and 15,400, depending upon the size of the microprocessor memory.

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ALTERNATIVES

FIGURE 59

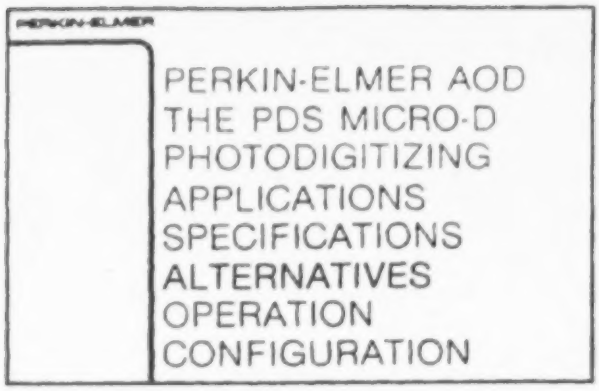
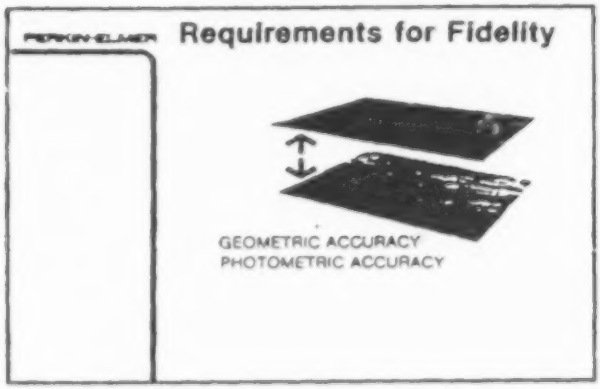
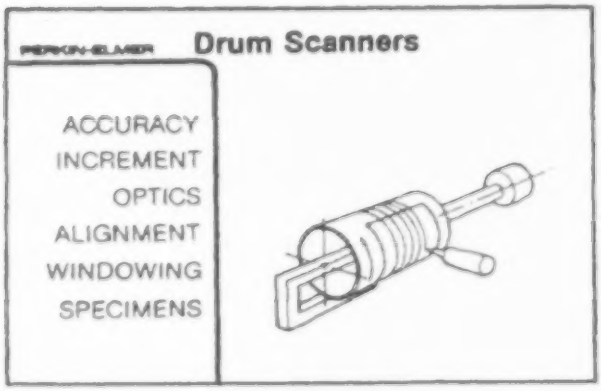


FIGURE 60



We will now survey some alternative scanning techniques to determine how well they meet the fidelity requirements of a correctly-sized aperture, sampled at the proper location, and an accurate measurement of photon flux.

FIGURE 61



Problems with drum scanners include:

- Verification of geometric accuracy. How does t manufacturer demonstrate conformance with h specifications?
- Matching of sampling increment to the actual pixel size. For a typical 4½ inch diameter drum, there are 360,000 microns in the circumference What is the resolution of the rotary encoder us to monitor the drum position?
- There is no room inside the drum for a proper optical system. What are the characteristics of the optics used?
- There is no viewing screen, so specimen alignment is difficult. If a specimen had to be scanned at an angle to the edge of the film, ho would it be mounted?
- Can several small areas be digitized, or would the entire specimen have to be scanned?
- Finally, can rigid or very small specimens be scanned?

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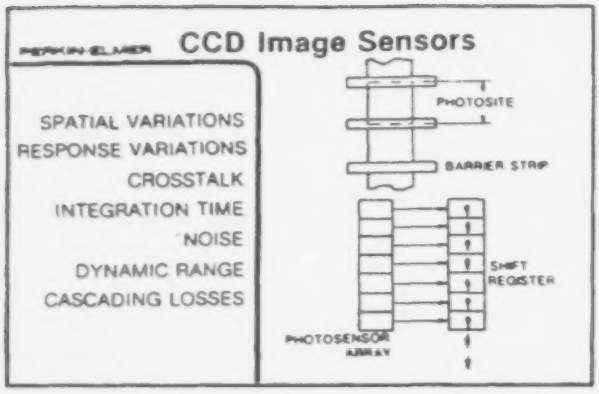
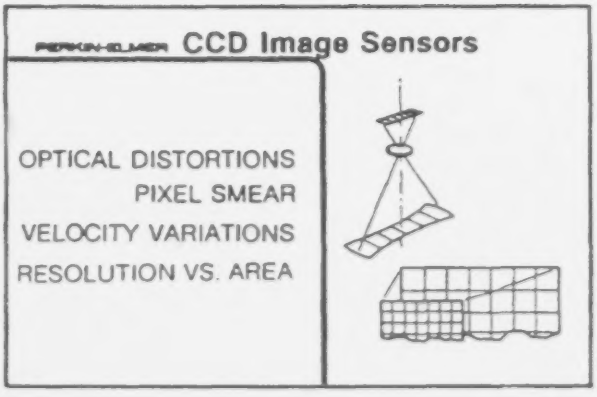
FIGURE 62



CCD image sensors exhibit a number of characteristics which inhibit the accurate measurement of photon flux

- Each photosite in a CCD array is separated from adjacent photosites by barrier strips. Therefore, photons from a uniformly-exposed pixel are not uniformly absorbed by the CCD photosite.
- Photosites in an array can vary in photometric response by 15 percent or more, requiring an individualized correction for each pixel measured.
- Since no source aperture can be used to restrict flare light, photosites will be affected by the level of illuminance incident upon adjacent pixels.
- A CCD image sensor photosite works by building up an electrical charge proportional to the number of photons absorbed. The absolute value of this charge is, therefore, a function of time as well as of illuminance. This introduces another variable in the photometric process.
- Each individual charge packet must be amplified to a useful level before being digitized. This process is inherently noisier than when using a PMT as a photosensor.
- The useful dynamic range of a CCD image sensor equals the saturation charge level divided by the peak-to-peak noise level. This ratio is typically no greater than 256 to 1.
- The transfer efficiency of these devices is such that a 2 percent error gradient can be imposed on the photometric values of each scan line

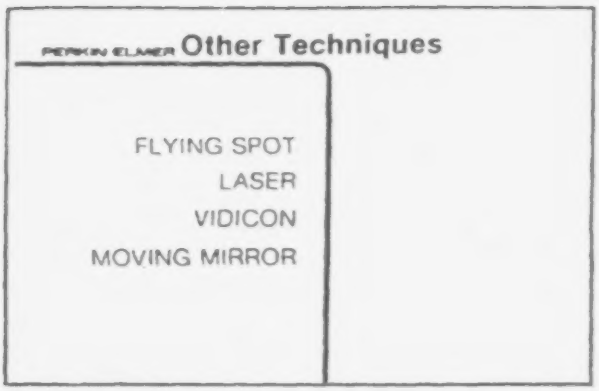
FIGURE 63



Further problems encountered when using a CCD image sensor array include:

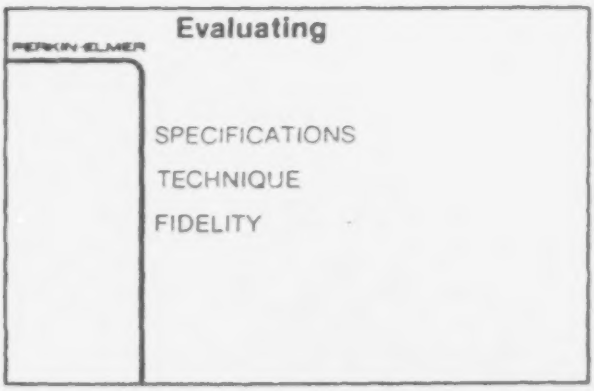
- Optical distortions which are inescapable when imaging far from the optical axis. To demonstrate this, scan a specimen with a CCD linear array. Then shift the specimen laterally so that the next scan overlaps the first by half of the CCD array length. Then compare the digitized values of corresponding sampled areas.
- Since each photosite must absorb photons for an extended period of time — typically a millisecond or more — any relative movement between the specimen and the photosite will cause smearing of the photometric reading. When a continuous scan is employed, this pixel smear can be as much as 100 percent.
- Any variations in an otherwise constant-velocity scan will induce photometric and geometric errors also, since sampling is usually time-based with these arrays. And often, the only way to achieve high spatial resolution when using a CCD image sensor is to increase the optical magnification ratio, thereby reducing the area being scanned

FIGURE 64



Several other techniques can be used for photodigitizing, but none provides the combination of geometric and photometric accuracies needed for high-fidelity work. All of the examples shown suffer from having an ill-defined sampling area which changes in size and shape as it is scanned across the specimen. They have no precise method of establishing the locations of the sampled areas, either. Off-axis optical distortions compound these problems. The photometry employed by these scanners is also usually characterized by high noise and low resolution.

FIGURE 65



To evaluate a particular instrument to be used for photodigitizing, first review the specifications. See if they meet your application requirements. Then consider the scanning technique used. Is it likely that the advertised performance can be delivered? Or are there inherent geometric or photometric problems in the method chosen? Remember, the only criterion of performance is the fidelity with which the numerical image generated by the instrument resembles the specimen scanned.

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This paper contains a review of techniques for remote sensing of human body shapes for the production of anthropometric data. The suitability of techniques for generating data for computer-aided design and manufacturing systems is discussed. Stereo photogrammetry, Moiré photography, laser imaging and sonic digitization are examined.

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